

METALLURGIA

The British Journal of Metals

(INCORPORATING THE METALLURGICAL ENGINEER)

Readers are invited to submit articles for publication in the editorial pages; photographs and/or drawings suitable for reproduction are especially welcome. Contributions are paid for at the usual rates. We accept no responsibility in connection with submitted manuscript. All editorial communications should be addressed to The Editor, "Metallurgia," 31, King Street West, Manchester, 3.

PRINCIPAL CONTENTS IN THIS ISSUE:

	Page		Page
The Iron and Steel Industry	291	Recent Developments in Materials for Gas Turbines	316-320
Britain Can Make It	292	<i>Materials are regarded as of the utmost importance in the development of gas turbines. A summary of some of the developments in the field of high-temperature materials is given, as discussed by Dr. T. A. Taylor in a recent symposium.</i>	
New Prices for Tin	292	Protection of Zinc Surfaces by Phosphating	320
Ferritic Discs for Gas Turbines. By D. A. Oliver, M.Sc., and G. T. Harris, M.A.	293-295	The Welding of Light Alloys	321-324
<i>Austenitic steels were initially used for discs in the jet propulsion gas turbine; but following intensive research and running tests, there has been a steady trend towards ferritic steels.</i>		<i>A symposium organised by the British Welding Research Association recently.</i>	
Cadmium Plate and Passivated Cadmium Plate Coatings. By E. E. Halls	295-297	Technics of Soviet Iron and Steel Industry. By I. Bardin	325-326
<i>The more general adoption of cadmium plating is now possible, but it should be used for purposes for which it is most suited, and the plating must be sound.</i>		The Institute of Welding	327-328
Symposium on the Failure of Metals by Fatigue	298	<i>Expansion of scope and activities.</i>	
Some Aspects of Nitriding. By S. A. J. Sage	299-303	The Geology and Mineral Resources of British Guiana	328
<i>The author shows how variations in nitriding results occur in the finished product despite the fact that every attempt has been made to follow instructions.</i>		Convention of British Steel Founders	329-330
Ductility of Metals and Alloys Used in Construction, II. By Dr. Georges Welter	304-310	The History and Present Status of Emission Spectroscopy as Applied to Industry. By John Convey, F.Inst.P.	331-335
<i>In this part are discussed the results of an investigation made on construction materials to establish a classification, with respect to their ductility, of light metals in comparison with other heavy structural materials.</i>		<i>The background is presented upon which spectroscopy in industry has been established as a laboratory control.</i>	
A Post-War View of Alloy Steels in the United States. By Robert S. Archer	311-315	Nature Printing Aluminium Alloy Forgings	335
<i>New levels of performance seem attainable as a result of greater knowledge of the conditions necessary for maximum combinations of strength and toughness in steel.</i>		Some Recent Appointments	336
		Apparatus for Quantitative Inorganic Micro-Analysis, I. By Ronald Belcher and Cecil L. Wilson	337-340
		<i>Much apparatus for microchemical work can be made by anyone having an elementary knowledge of glass-blowing. The construction and range of apparatus for gravimetric analysis is described and notes are given on its use.</i>	
		Metallurgical Digests	341-346

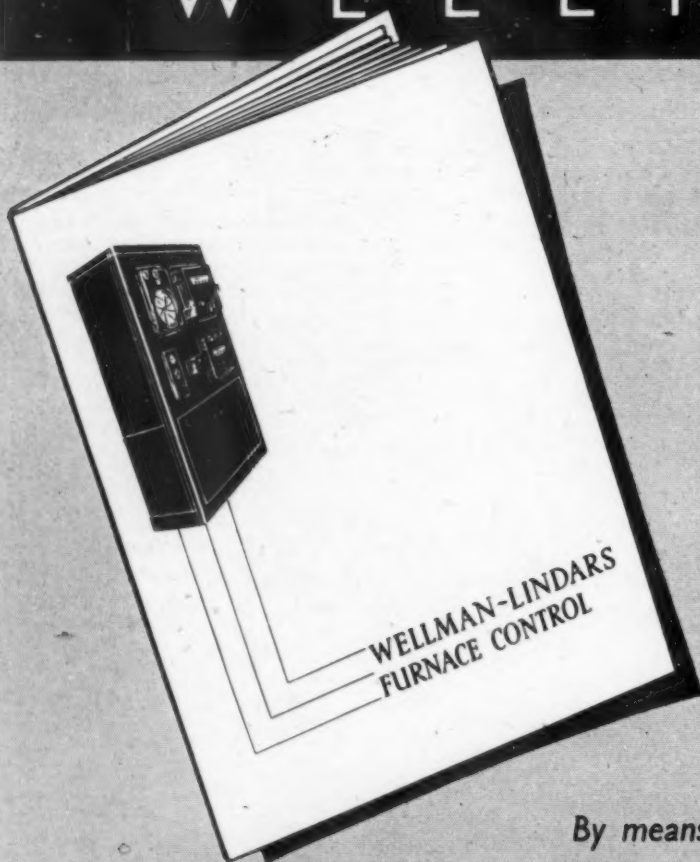
Subscription Rates throughout the World - - 24/- per annum, Post free

Published monthly by THE KENNEDY PRESS, LIMITED.

REGISTERED OFFICE: 31, King Street West, Manchester, 3.
Telephone: BLA 2084. Telegrams: "Kenpred," Manchester.

LONDON OFFICE: Bedford Street, W.C.2.
Telephone: Temple Bar 2629.

W E L L M A N



A New Development in Furnace Control

By means of the Wellman-Lindars

Furnace Control System a solid fuel fired furnace

*can now be operated entirely automatically with the precision usually
associated with gas firing. We invite you to write for a copy
of our brochure giving details of this new development.*

COMBUSTION RATE VARIED AUTOMATICALLY WITH FURNACE OUTPUT
CONSTANT TEMPERATURE MAINTAINED INDEFINITELY

||
RESULTING IN
||

IMPROVED QUALITY OF FINISHED PRODUCT

FUEL ECONOMIES UP TO 30%

THE WELLMAN SMITH OWEN ENGINEERING CORPORATION LTD.
VICTORIA STATION HOUSE VICTORIA STREET, LONDON, S.W.1

WORKS DARLASTON, SOUTH STAFFS, ENGLAND

METALLURGIA

THE BRITISH JOURNAL OF METALS.

INCORPORATING "THE METALLURGICAL ENGINEER."

OCTOBER, 1946

VOL. XXXIV No. 204

The Iron and Steel Industry

POLITICAL trends at the present time are moving towards increased State intervention in, or ownership of, industry. Legislation for the nationalisation of transport and power is promised and it is probable that cotton will occupy a high position in the list for future nationalisation. Until recently it was thought likely that the life of the present Parliament would see the nationalisation of the greater part of the iron and steel industry. This trend towards public ownership of all the means of production is obviously controversial from an economic as well as a political point of view; fundamentally the issue is how far and in what respects shall the State intervene in the conduct of industry by private enterprise.

The complexity of the iron and steel industry in particular makes any movement towards complete nationalisation of this industry very difficult indeed, quite apart from any advantages or disadvantages such a system may have, and it is not surprising that the original idea for full nationalisation is not now advocated so strongly by the Government. Consider the main trade associations or "Conferences" as they are now termed, which are affiliated to the Iron and Steel Federation. There are eleven of these and they relate respectively to the production of pig iron; steel; steel sheets; tinplates; hot-finished tubes; wire and wire rods; heavy forgings and railway tyres, axles, solid wheels and disc wheel centres; alloy and stainless steel; crucible and high speed steel; light rolled sheet products; and bolts, nuts, screws, and rivets. Even these eleven departments of the industry comprise some 500 firms.

The conferences do not exhaust the number of trades making iron and steel products which can be classified as crude or finished steel. It should be remembered that while some forty different firms make pig iron and about fifty make carbon steel, practically all are also engaged in the later processes of the industry, rolling sheets or sections, making tubes or the lighter rolled products; many, indeed, are responsible for quite a variety of products. In effect, the industry spreads out fanwise as it proceeds from the crude to the finishing ends. In comparison with the relatively small number of firms making pig iron and steel, there are many hundreds rolling light products. The processes are so interwoven that a single firm may operate every one, including coke ovens, blast furnaces, steel furnaces and rolling mills and other plant for the production of sheets, joists, rails, sections of all kinds, merchant bars and rods, etc. Some of the large firms extend further—to structural work and bridge building. Thus, it will be seen that the British iron and steel industry is integrated vertically and drawing a demarcation line to determine which is concerned with the production of steel, which was intended for nationalisation, and engineering, which at

the moment is considered to be outside the scope of this system of control, would seem to be impossible.

That some modification has been made to the original plan is apparent from a recent statement by Mr. Wilmot in which he referred to a large share of public ownership of the industry. Indeed, the Government has decided to introduce an Enabling Bill next year under which it would be authorised to acquire compulsorily the majority of the share capital of any company in the industry, either through the purchase of existing shares or through the creation of additional shares. It may be that the Government will make itself responsible for financing the constructive proposals given in the Iron and Steel Federation's report and subsequently issued by the Government as a White Paper. These far-reaching proposals are estimated to cost £168 million spread over a period. On the other hand it has been stated that some 20 large firms control about 90% of the production of steel and that a controlling interest in these firms would suffice. Either method of acquiring control would seem simple, but on close examination of the real structure of the industry, the difficulty of drawing a dividing line will be apparent.

It is probable that the large measure of public ownership now contemplated is an endeavour to find a more moderate solution to what is recognised as a very thorny problem. In this way it may be possible to retain all the advantages of private enterprise and also have a more stable industry through Government control. Much depends on the Iron and Steel Board under the chairmanship of Sir Archibald Forbes and, so far, comprising Sir Alan Barlow, Mr. G. H. Latham, Mr. Richard Mather, Mr. Lincoln Evans and Mr. Calligan. It would be easy to criticise the constitution of the Board as only two members—Mr. Latham and Mr. Mather—have an intimate knowledge of the industry and its management, but judgment should obviously be deferred until the results of their work become manifest. That they have a difficult task, few will deny, and it is hoped that political considerations will not interfere with the sound reconstruction of the industry that will be beneficial to the country as a whole.

There is a tremendous amount of work to be done to improve the various plants and to raise the steel production capacity of the country to assist in meeting the increased demand. The present steel ingot capacity of the country is stated to be 14,100,000 tons; in practice 13,250,000, because of maintenance delays, etc. Production during the first, second and third quarters of this year, on an annual rate basis, was 12,617,000, 13,111,000 and 11,953,000 tons respectively, and shows that the industry is working near to practical capacity. The developments and reconstruction contemplated is designed to raise steel production capacity to 15,950,000 tons. It will be some considerable time before this increased capacity can be made available, but it is for

the Board to get busy without undue delay to put the industry in a position to increase supplies. Whether the reconstruction contemplated will lead to any great initial saving in production costs is very doubtful, because of the present high level of prices, including the cost of new buildings and plant, but as time goes on and existing plant becomes more costly to maintain, the saving in production costs will become more apparent.

In order to foster a more stable industry in this country it has been customary over many years to import semi-finished steel to maintain a balance between supply and demand. This practice has been continued, but, while supplies were formerly available from the Continent, the

change in conditions has caused the Government to seek supplies in the United States and Canada. Internal difficulties in those countries, however, have greatly reduced the amount expected from these countries, in consequence and due to the greater demand for steel for other purposes, the Ministry of Supply has curtailed the 1947 supply of sheet to the motor trade. This, of course, will have repercussions on our trade, but it is only one example of the dependence of industries upon the production of the iron and steel industry and the sooner concentrated efforts are applied to place this industry on a sound basis the quicker the trade of the country will be re-established.

Britain Can Make It

THE King laid special emphasis on the excellence of workmanship and design when he opened the Britain Can Make It Exhibition. All those who had the good fortune to visit this Exhibition will endorse the view expressed by His Majesty and will appreciate that the skill and initiative, for which the British have been noted for centuries, remain of a high order and in some directions are unsurpassed to-day.

We are apt to forget that British ingenuity and skill in industry are not of recent origin. From early in the 18th century, when the hand spinning wheel, the hand loom and the plough had remained unchanged from very early days, the demand in England for more and cheaper goods has acted as a spur to invention. It was about this time that the first great series of mechanical inventions began. In 1733, for instance, Kay patented the flying shuttle; this was followed in 1764 by the invention of the spinning jenny; but a new principle was introduced by Arkwright, who spun a finer and stronger thread. The principles of these latter inventions were later combined by Crompton in designing the mule, which produced a still stronger and finer yarn. In 1785 Cartwright invented the first practical mechanical loom, to be followed shortly afterwards by his machine for wool-combing. It was not until 1815, however, that the loom was perfected and came into general use. These new machines needed a new power. Horse power was not unknown, but it was the use, first of water and then, through the inventions of James Watt, of steam, that ushered in an era of industrial activity.

Development of England's mineral resources, checked in the 17th century for the lack of steam power now proceeded apace. Darby had discovered that iron could be smelted with coke and the new era was ushered in by the use of Smeaton's blast furnace in the Carron Iron Works in 1760. Wilkinson applied iron for the construction of bridges and in 1790 launched an iron ship. There seemed no end to the uses of iron and steel, first cast by Huntsman at Sheffield in 1740. Cort's invention of puddling, in 1783, and shortly afterwards his use of rollers in the making of iron bars, further increased development.

This brief reference to early British discoveries indicates the background of initiative, skill, and enterprise upon which British industry is built. That the flair for these qualities is still inherent in the nation is indicated by the Exhibition, indeed through its long industrial history discoveries and development have been continuous, and the initial qualities demonstrated persist to-day enabling Britain to maintain its high tradition for excellence of design and manufacture. The

engines of one British firm, for instance, whether the design is for aircraft or motor cars, are considered to be the best in the world. In jet propulsion, too, Britain leads the world.

It is unfortunate for the British that the best of Britain's products are for export; the home demands cannot be satisfied until a reasonable trading balance has been established, but there is some satisfaction in knowing that they fill a need elsewhere and will be appreciated. Certainly the Exhibition proves that Britain can make it and continues in the forefront in the application of science to industry.

New Prices for Tin

SHORTLY after agreement had been reached between the Reconstruction Finance Corporation and the representatives of four groups of Bolivian producers, the Ministry of Supply announced a new basic price for tin metal sold by the Non-Ferrous Metals Control. For delivery in the United Kingdom the basic price of the metal has been increased from £300 to £380 10s. per ton, while the basic price for metal sold f.o.b. for export from a United Kingdom port has been increased from £357 to £380 10s. per ton. These prices are for metal having a minimum 99% to 99.75% tin content, and prices for all other grades vary correspondingly.

These prices have been fixed as a result of settlement reached on the purchase price to be paid by the Ministry of Supply for tin concentrates in Malaya, Nigeria and East Africa. In the case of Nigeria where the costed contracts with the main producers terminated at the end of 1945, the price for the first half of 1946 was fixed at £340 per ton of tin in ore f.a.s. Nigerian port, and for the second half of 1946 at £357 10s. per ton of tin in ore f.a.s. Nigerian port. The prices paid in East Africa generally are on the Nigerian levels. In the case of Malayan concentrates the basic tin price from July 1, 1946, is £370 a ton at Penang/Singapore smelters.

World tin production in the first half of this year amounted to 43,250 long tons, or about 54% of the average half-yearly production in the years 1934-1938 inclusive, and about 36% of the average half-yearly production in 1941 when output reached its peak. Seeing that the yearly average of world apparent consumption during 1934-1938 inclusive amounted to about 156,560 tons, a definite scarcity exists at a time when the world demand for the metal must be greatly increased. Whether there will be increased production in the immediate future is doubtful, but the increased prices to producers will ultimately lead to increased production.

Ferritic Discs for Gas Turbines

By D. A. Oliver, M.Sc., F.I.M., F.Inst.P., and G. T. Harris, M.A., F.Inst.P.

(Research Department, William Jessop and Sons, Ltd., Sheffield)

Of the many materials developed to facilitate the development of the jet propulsion gas turbine, not the least important are those which have been applied for the turbine discs. Initially austenitic steels only were used for this purpose but, as a result of intensive research and extensive running tests, there is also a growing use of ferritic steels. Particulars are given of four brands of steel of this type, together with their properties, which have been developed for gas turbines, and brief reference is made to the manufacture of turbine discs from these steels.

AN outstanding phase of engineering progress in recent years has undoubtedly been the rapid development of the internal combustion gas turbine or jet engine for modern aircraft. This development owes much to the pioneer work of Air Commodore Frank Whittle, C.B.E., and to the early labours of A. A. Griffith and Hayne Constant, of R.A.E., Farnborough, but during the last five years most spectacular advances have been made by the British aero-engine firms. It is probably true to say that all the British aero-engine firms are now actively developing gas turbines of various kinds. However, it should not be forgotten that much original research, vital to the rapid rate of progress, has also been conducted at the Government-owned establishment known until recently as Power Jets (Research and Development), Ltd., and now reconstituted as the National Gas Turbine Establishment.

In 1941, Major Halford and his distinguished colleagues designed their first jet-propulsion engine, which is now well known as the "Goblin." This engine, at present manufactured by the De Havilland Engine Co., Ltd., is distinguished by one feature which deserves separate comment. A ferritic, as distinct from an austenitic, steel turbine disc was introduced and has been standardised in all subsequent De Havilland gas turbines. That feature is of cardinal interest because the choice of ferritic turbine discs by this firm has done much to stimulate research in Great Britain into steels of this type.

Advantages and Disadvantages of Ferritic Discs

The advantages of ferritic discs are:

- (1) At temperatures below 350° C. proof stresses (0.1% strain) in the range 40/55 tons per sq. in. can readily be obtained after hardening

and tempering, and thus weight can be reduced for a given diameter.

- (2) Thermal expansion coefficients are a minimum and therefore thermal stress effects are reduced.
- (3) Forging and heat-treatment operations present no special difficulties.
- (4) Reproducibility of sound forgings is comparatively easy.
- (5) Machinability problems are not unduly difficult.
- (6) Low alloy steels are attractive economically.

The disadvantages of ferritic discs are briefly:—

- (1) The creep strength for a stated strain falls rapidly for most steels over 550° C. and therefore over-heating can prove serious for a given stressing.
- (2) Notch-sensitivity effects are generally greater than for austenitic steels below 400° C.
- (3) Weldability is generally difficult.

It is seen that nearly all of the disadvantages can be side-stepped by design and by controlling the operating conditions in the engine. The most important control which must be exercised is that of preventing over-heating of the rim in the neighbourhood of the rotor blade roots.

Steel Research at Elevated Temperatures

In 1938, work was commenced in the Research Department, William Jessop & Sons, Ltd., Sheffield, on the mechanical properties of high- and low- alloy steels in the temperature range of 500° C. to 950° C. Special equipment had to be devised, some of which has now been described,* and much attention has been devoted to obtaining the creep characteristics of different materials at temperatures ranging from 500° C. to 850° C.

Early opinions regarding the scaling of ferritic turbine discs under practical engine conditions proved over-cautious,

* Harris, *Metallurgia*, Vol. 34, July, 1946, p. 129.

so that historically there has been a steady move from more scale-resisting alloy steels to the less scale-resisting ones. Furthermore, for certain critical machining operations, notably blade-root broaching, some steels proved more attractive than others, and thus alternative steels have been granted extensive running trials on the engine test-beds.

The properties of four well-known Jessop Steels are tabulated in Tables I and II, which include composition, heat-treatment, and mechanical properties at room and elevated temperatures. The information in Table II has taken considerable time to accumulate and should prove of special value to gas turbine designers. Additional necessary data is recorded in Table III.

TABLE I.
PROPERTIES OF JESSOP DISC STEELS.
(CHEMICAL COMPOSITION AND MECHANICAL PROPERTIES).

JESSOP BRAND	H.3A	H.27	H.31	H.40
<i>Chemical Composition</i>				
Carbon	0.6	0.4	0.4	0.25
Manganese .. .	0.5	0.6	0.4	0.4
Silicon	1.2	0.3	0.3	0.4
Chromium .. .	6.0	3.0	1.1	3.0
Molybdenum ..	0.5	0.8	0.7	0.5
Tungsten .. .	—	—	—	0.5
Vanadium .. .	—	0.2	—	0.75
<i>Mechanical Properties at Room Temperature</i>				
Heat Treatment: Oil Quenching				
Temperatures ..	980° C.	900° C.	800° C.	1060° C.
Tempering Temperatures ..	740° C.	650° C.	630° C.	670° C.
0.1% Proof Stress (Tons/sq. in.) ..	45	50	43	50
Maximum Stress (tons/sq. in.) ..	60	60	58	60
Elongation % (L = 4√A) ..	20	18	20	18
Reduction of Area % ..	40	40	40	45

It will be seen from Table I that all of the four ferritic steels give proof stresses of not less than 40 tons per sq. in. at room temperature, associated with a maximum stress of 55/65 tons per sq. in. These properties can be secured either radially or tangentially

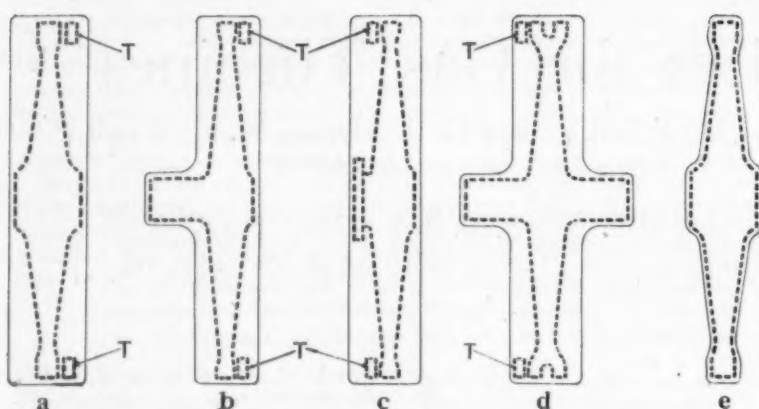


Fig. 1.—Sectional elevations of typical disc forgings.
T=Test Ring

near the rim of the disc forging, and even at the centre the properties are well maintained provided skill is exercised in manufacture and a suitable forging technique adopted. A minimum elongation of 15% over the body of the disc forging can also be obtained. Mechanical properties are, however, slightly lower at the centre of the turbine disc under normal conditions.

TABLE II.
PROPERTIES OF JESSOP DISC STEELS.
[CREEP STRESS (TONS/SQ. IN.) FOR 1% STRAIN IN
300 HOURS].
(Test pieces from actual six forgings).

JESSOP BRAND	H.3A	H.27	H.31	H.40
Temperature				
500° C. ..	11	22	29	26
550° C. ..	5.3	12.5	16	21
600° C. ..	2.8	5.5	6.3	13.5
650° C. ..	—	—	—	6.5

TABLE III.
PHYSICAL PROPERTIES OF JESSOP DISC STEELS.

JESSOP BRAND	H.3A	H.27	H.31	H.40
Coefficient of Linear Thermal Expansion × 10 ⁻⁶ per ° C.				
20° to 100° C. ..	12.1	12.5	12.3	12.4
20° to 500° C. ..	12.3	12.9	12.6	12.4
20° to 300° C. ..	12.4	13.2	13.2	12.5
10° to 400° C. ..	12.8	13.5	13.7	12.9
20° to 500° C. ..	13.1	13.8	14.1	13.2
20° to 600° C. ..	13.3	14.0	14.4	13.6
20° to 700° C. ..	13.4	14.2	14.6	13.9
Specific Gravity	7.76	7.83	7.85	7.84
Thermal Conductivity C.G.S. Units				
Mean Temperature.				
100	0.06	0.09	0.10	0.08
300	0.07	0.09	0.10	0.08
500	0.07	0.08	0.08	0.08
700	0.06	0.07	0.07	0.07

In Table II it will be noted that there are marked differences in the creep strength of the four steels, the order of excellence at 550° C. being H.40, H.31, H.27 and H.3A. However, as regards scaling resistance, the order is almost reversed in that H.3A excels and H.31 is the least scale-resistant. Care must therefore be exercised in choosing the

best balance of performance characteristics for a given turbine stage.

A matter of paramount importance is what might be termed metallurgical stability. All the steels described are oil-quenched, and tempered at temperatures ranging from 630° C. to 740° C. It is broadly desirable that the tempering temperature should exceed the working engine rim temperature by as large a margin as possible, and that the sorbitic-troostitic structure of the hardened and tempered disc should resist softening (with consequent lowering of proof stresses) on prolonged heating at the operating temperature. As might be expected from its lowest tempering temperature, H.31 steel is the most susceptible to secular softening and must be used with due regard to this effect in spite of its excellent showing on creep strength. On the other hand, the vanadium-bearing steels are particularly satisfactory as regards secular softening and H.3A is also very stable.

The Choice of Steel for a New Turbine

A careful study of Tables I and II would indicate reasoning on the following lines. For a

very highly stressed disc running at the highest temperature the first choice would be H.40. If operating root temperatures are nearer 500° C. than 550° C. then the next selection would be H.27 or H.31, probably the former on account of its superior secular metallurgical stability and scale resistance. If, however, evidence has been obtained that the degree of softening during a typical working life was not serious, the preference would be for H.31 as being slightly easier to machine than H.27 and as having an extra margin on creep strength. H.3A, which has high scale-resistance and lower creep strength, is not expected to be the best compromise for future turbines in which working temperatures are being stepped-up. By way of interest, H.40 is similar to the steel used in the German Junkers Jumo 004 jet engine. The first steel of this type, I.G.F. N10, was originally used for tubes for oil refineries. An important characteristic of H.40 steel, when hardened and tempered, is that it has proved on test to be notably free from "notch-sensitiveness" in alternating stress fatigue, and is an outstanding exception in the ferritic class of steels. On account of its low carbon content it can be regarded as weldable, provided

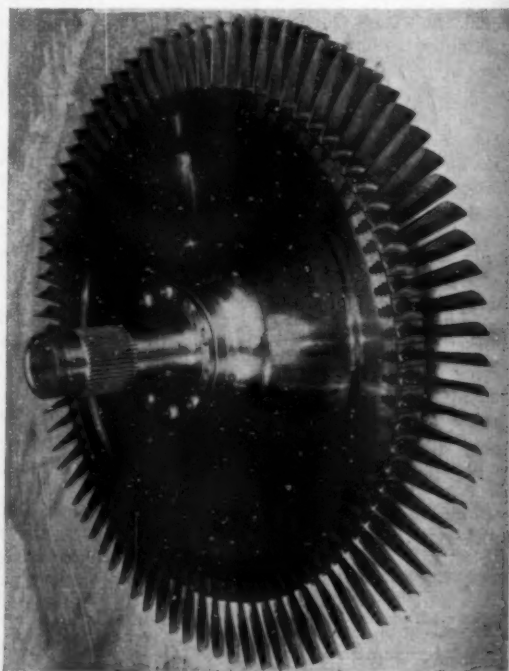


Fig. 2.—Finished turbine disc from a "Goblin" jet engine complete with rotating blading.

due care is taken to stress-relieve immediately after welding. Welding of the other steels is not recommended.

Examples of Ferritic Turbine Discs

A primary objective in disc production is to cast an ingot of electric-arc furnace steel having the most dense axial structure free from major segregation and gas porosity. Many precautions have to be exercised to secure this result, in both steelmaking and casting pit practice. Suffice it to say that attention is given to all factors affecting ultimate quality, and ample discards are made at all stages. Great care is taken to immunise ingots and forgings by cyclic heat-treatments against the occurrence of hair-line cracks.

The ingot is first drawn down by forging to hot-work the whole structure and this operation is followed by annealing and any precautionary heat-treatments. When cold, the resulting

bloom is machined into "cheeses" which are then "upset" by a second operation into rough forged discs. In Fig. 1 are shown sectional elevations of representative disc forgings. In (a) and (c) the finished disc is machined from a straight-sided disc forging. In (b) and (d), short stub-shafts are forged integral and splined to engage with the main blower shaft. In (e) is seen a drop-stamped disc form which, while somewhat easier to machine, does not allow of the provision of a ring of test material from the blade root region. The outer zones of the discs are all so well hot-worked by the upsetting operation that forging grain flow has not emerged as a critical factor, and all procedures shown in Fig. 1 can be regarded as equally satisfactory.

In Fig. 2 is seen a finished turbine disc from the "Goblin" jet engine† complete with rotating blading. This engine is now rated in production at

†E. S. Moult, *De Havilland Gazette*, February, 1946, p. 6.

3,000 lb. static thrust and is outstanding in its class.

Turbine discs up to 30 in. in diameter and 6 in. thick have been produced. Larger sizes can confidently be attempted when once the need arises. Rotor forgings of the axial-flow steam-turbine type can also be produced in the special steels already described, which have proved so successful in discs. Long-time creep data at lower stresses over very extended periods are also being accumulated. The next decade will doubtless show much progress in the internal combustion gas turbine with its associated special material, if only a little of the present rate of advance be maintained.

The authors wish to acknowledge a valued and extensive co-operation with Major Halford and his colleagues of the De Havilland Engine Co., Ltd., and for permission to reproduce Fig. 2 and to refer to "Goblin" engine developments.

Cadmium Plate and Passivated Cadmium-Plate Coatings

By E. E. Halls

During the war the use of cadmium as a protective medium was limited due to the relatively small quantities available. To-day the position is different and the more general adoption of cadmium-plating is possible, but it should be used for purposes for which it is most suited and, for satisfactory performance, the plating must be sound. Results of tests, which are described, indicate a method of processing which will give satisfactory performance.

CADMIUM as an electroplate coating for metal components has long since been recognised as a protective medium competitive with zinc. Even in normal times, however, the quantity of cadmium is limited, and its cost is high compared with that of zinc. It is, therefore, neither practicable nor desirable to replace zinc by cadmium in all applications where electro-deposited protective coatings are used. During the war years, the amount of cadmium reaching this country has been relatively very small and it has been reserved for essential purposes, particularly in the production of alloys. Industrial cadmium-plating has therefore receded to very small proportions. To-day, the situation is different, and the more general adoption of cadmium-plating becomes possible. It is important to ensure that the process becomes exploited for purposes for which it is most suited, and that in such applications it is used to the best advantage.

One of the shortcomings of zinc coatings is their propensity to grow white corrosion compounds, particularly under conditions of dampness. This failing is particularly marked with electro-deposited zinc coatings, which are more porous than say, hot-dipped coatings applied by galvanising. It has been found by experience over the last few years that this type of deterioration can be prevented, or at least retarded to a degree that it

is virtually non-existent, by a process termed passivation. This is a very simple immersion treatment at room temperature in an aqueous solution containing chromates.

Cadmium coatings are usually denser than zinc coatings, but nevertheless they deteriorate in much the same way as zinc deposits. The progress of corrosion is not quite the same, and under humid conditions it may not be gradual. Often a period of no attack is experienced, followed by sudden breakdown with the growth of copious white corrosion products. It is interesting to note that exactly the same passivating treatment can be applied to electro-plated coatings of cadmium as to those of zinc. The degree of added protection afforded by this treatment is even greater than that experienced with zinc platings. The following briefly summarises test results of a typical nature to illustrate this fact.

Test pieces of mild steel to represent the ferrous metals, and of brass and copper to cover the non-ferrous materials, were used. They were cleaned and cadmium-plated through the normal types of industrial processes. In practice, cadmium coatings are usually dipped immediately after electroplating, either in an aqueous solution of plater's compound, or in a lanoline-base solution.

The object of this treatment is to give protection to

cadmium against marking by handling and against deterioration by dampness. Consequently, half the specimens were treated in this manner, using the dip in a solution of plater's compound, and the other half were passivated by a standard chromate process.

A thickness of cadmium coating from half to three-quarters of a thousandth of an inch was aimed at, and representative specimens were used to check the average cadmium thickness on the test specimens. Two types of durability test were applied. One of them consisted of the heat and humidity cycles of W.T. Board specification K.110. In detail, this comprised one cycle of dry heat consisting of 6 hours exposure at 71° C., cooling off in the test cabinet for the remainder of the 24-hour day, followed by 20 cycles of wet heat, each of which consisted of 6 hours at 60° C. and 100% humidity with cooling in the test cabinet for the remainder of the 24 hours. The second test was a standard salt spray exposure. This involved subjecting the samples to the mist produced by atomising a 20% salt solution with clean, moist compressed air at room temperature. The specimens were left in the test chamber for 24 hours, 8 hours with the atomiser operating, and 16 hours in the mist-laden atmosphere. At the start of each day, they were washed in clean, running cold water and dried with a soft cloth for examination.

Brief details of the finishing processes used are as under :—

(a) *Degreasing.*

The major oil and grease was removed in a trichlorethylene vapour degreaser.

(b) *Alkali Cleaning.*

Final traces of grease and loose dirt were removed in a hot mild alkali solution, using 4 oz. of soda ash and 4 oz. of sodium metasilicate per gallon of water. This was followed by two cold water washes.

(c) *Acid Cleaning.*

The work, without allowing to dry from (b), was given an acid treatment. The steel specimens were given a 1 min. immersion at room temperature in equal volumes of concentrated hydrochloric acid and water. This was followed by two cold water washes. The brass and copper samples were given a bright acid dip. This comprised immersion at room temperature for a few seconds in a mixture of three parts nitric acid and one part sulphuric acid. A quick cold water rinse followed and then a few seconds immersion in a mixture of one part nitric acid and three parts sulphuric acid. Two cold water washes followed.

(d) *Neutralisation Rinse.*

Work still wet from the water washes after acid treatment, was rinsed for a few seconds in a 5% cold solution of sodium cyanide. It was then given a cold water rinse.

(e) *Cadmium-Plating.*

The specimens without allowing to dry from (d) were inserted in the cadmium-plating vat and plated for the requisite time at 10 amps./sq. ft. of cathode surface. The electrolyte was prepared from :—

Cadmium Oxide 5 oz.

Sodium Cyanide 12 oz.

Water 1 gal.

Two thorough cold water washes followed.

(f) *After-treatments for Specimens not Chromate Passivated.*

The work still wet was immersed in a 5% solution of cream of tartar at room temperature and then in a hot solution of 5% plater's compound. Finally, it was dried off in hot sawdust.

(g) *After-treatments for Specimens Chromate Passivated.*

The work still wet from the washes after cadmium-plating was immersed in the passivating solution for 10 secs. at room temperature. It was then given two cold water washes and dried off in hot air at a maximum temperature of 160° F.

The passivating solution is the same as that used for zinc plate, and is covered by D.T.D. Spec. 923. Normally, it comprises 200 grns. of sodium dichromate crystals and 6.6 ml. of concentrated sulphuric acid per litre of water. Operating limits are 150–200 grns., and 5.5–10.0 ml. for the two ingredients, respectively. The solution can be prepared from proprietary chemicals which usually contain an inhibitor that minimises attack on the cadmium or zinc. Such proprietary products may be in solution or solid form, and they function very satisfactorily. One of them was used in this instance.

TABLE NO. I.—AVERAGE THICKNESS OF CADMIUM-PLATE COATING ON SPECIMENS USED FOR DURABILITY TESTS

Average Thickness of Cadmium Plate	Base Metal		
	Steel	Brass	Copper
Expressed in inches	0.00064	0.00065	0.00065
Expressed in milligrams of cadmium/sq. in. of surface area	92	94	93

TABLE NO. II.—BEHAVIOUR OF CADMIUM-PLATED STEEL, PLAIN AND CHROMATE PASSIVATED, UNDER K.110 TEST CONDITIONS

Number of Wet Cycles	Behaviour of Specimens Under K.110 Test Conditions		
	Plain Cadmium-plated Steel	Chromate Passivated Steel	Cadmium-Steel
1.....	Deteriorated to a blackish appearance with light white corrosion superimposed.	No corrosion and appearance not impaired.	
2.....	Further deterioration to a dirty black appearance.	Unchanged.	
5.....	Appearance a very dirty black with marked spots of white corrosion products superimposed.	Very slight darkening of colour, but otherwise no deterioration.	
10.....	Little perceptible change.	A few tiny blackish spots near edges.	
15.....	Blackening and corrosion more intense.	No perceptible change.	
20.....	A few small rust spots, appearance intensely black, and condition very poor.	Darkening confined to areas near edges, main surfaces virtually unaffected. Condition exceedingly good.	

The thickness of plating on the specimens is shown by the data given in Table No. I. Tables Nos. II, III and IV give details of the behaviour of the steel, brass and copper specimens respectively, under K 110 test conditions. These impose heat and wetness, with the latter relatively pure, uncontaminated with electrolytes. The true passivating influence of the chromate treatment is emphasised in every case.

Tables Nos. V, VI and VII summarise the performance of the steel, brass and copper specimens respectively under the severely corrosive conditions of salt spray. These represent accelerated marine atmosphere conditions. Again the chromate process is shown quite clearly to provide passivation.

From the foregoing, it will be appreciated that very little additional processing effort ensures much improved

serviceability from the cadmium finish. The chromate passivating solution is inexpensive and simple to maintain by periodic analysis. It is only necessary to ensure the work passes to it straight from the plating process, to control the time of immersion, and to avoid overheating in drying the work. Hot water leaches inhibitive chemicals from the passive film, and hot-baking drives out combined moisture, both depreciating its value somewhat.

Cadmium is a sacrificial protection for iron and steel, and its use on these metals is logical. It is not normally used on brass and copper because the latter are too highly electronegative in relation to cadmium, rendering a heavy, non-porous coating of the latter essential for it to be durable. However, in many industries, particularly

TABLE NO. III.—BEHAVIOUR OF CADMIUM-PLATED BRASS, PLAIN AND CHROMATE PASSIVATED, UNDER K.110 TEST CONDITIONS

Number of Wet Cycles	Behaviour Under K.110 Test Conditions	
	Plain Cadmium-plated Brass	Chromate Passivated Cadmium-plated Brass
1.....	Cadmium finish deteriorated to a blackish appearance, and some white corrosion products	Entirely unaffected.
2.....	Deterioration more intense.	Ditto.
5.....	A very dirty black appearance, with loose white corrosion products superimposed.	Ditto.
10.....	A little further development of the attack.	A few isolated blackish areas developed, but generally the finish unimpaired.
15.....	Ditto.	Ditto.
20.....	General condition very poor, intense black discoloration and appreciable white corrosion products.	No perceptible change, and condition very good.

TABLE NO. IV.—BEHAVIOUR OF CADMIUM-PLATED COPPER, PLAIN AND CHROMATE PASSIVATED, UNDER K.110 TEST CONDITIONS

Number of Wet Cycles	Behaviour Under K.110 Test Conditions	
	Plain Cadmium-plated Copper	Chromate Passivated Cadmium-plated Copper
1.....	A dirty black appearance with some white corrosion products superimposed.	No visible deterioration.
2.....	Deterioration further developed.	Ditto.
5.....	Appearance very dirty black in colour, with general white corrosion spots superimposed.	Ditto.
10.....	No marked change.	A few isolated but small blackish areas apparent, but little significant deterioration.
15.....	Little further change.	No visible change.
20.....	No perceptible change, but general condition very poor.	No further deterioration. General condition very good.

TABLE NO. V.—BEHAVIOUR OF CADMIUM-PLATED STEEL, PLAIN AND CHROMATE PASSIVATED, UNDER SALT SPRAY TEST CONDITIONS

Period of Test in Days	Behaviour Under Salt Spray Test	
	Plain Cadmium-plated Steel	Chromate Passivated Cadmium-plated Steel
1.....	Cadmium attacked to give slight general white corrosion products.	Entirely unaffected.
2.....	Attack developed further.	Ditto.
15.....	Attack more intense, giving fairly heavy white corrosion products against a general dark-coloured background.	Colour slightly darker in a few local areas, but no corrosion, and condition very good.

those concerned with electrical communication equipments, such as radio, telephone and the like, the assemblage of a variety of components inevitably leads to numerous bimetallic junctions. These tend to promote corrosion due to local cells being set up under damp conditions. Electrical continuity may thereby be impaired, for example, at earthing points. This risk is minimised by reducing the electro-chemical dissimilarity at the junctions by electro-plating. In this way, it is

often useful to cadmium-plate copper and other non-ferrous alloys that have to be assembled to cadmium-plated steel components. It is for this reason that brass and copper have been included in the above test series.

Cadmium-plating is a useful protective finish for iron and steel. In the radio industry it is the preferred

TABLE NO. VI.—BEHAVIOUR OF CADMIUM-PLATED BRASS, PLAIN AND CHROMATE PASSIVATED, UNDER SALT SPRAY TEST CONDITIONS

Period of Test in Days	Behaviour Under Salt Spray Test	
	Plain Cadmium-plated Brass	Chromate Passivated Cadmium-plated Brass
1.....	Attack on cadmium commenced to give a general slight white coating of corrosion products.	Entirely unaffected.
2.....	Development of white corrosion a little more intense.	Ditto.
15.....	General white corrosion with a dark-coloured background.	A little slight darkening in a few areas, but no corrosion, and general condition very good.

TABLE NO. VII.—BEHAVIOUR OF CADMIUM-PLATED COPPER, PLAIN AND CHROMATE PASSIVATED UNDER SALT SPRAY TEST CONDITIONS

Period of Test in Days	Behaviour Under Salt Spray Test	
	Plain Cadmium-plated Copper	Chromate Passivated Cadmium-plated Copper
1.....	Cadmium attacked to form slight general whitening.	No deterioration.
2.....	Increase in intensity of attack.	Ditto.
15.....	White corrosion products quite general on a dark-coloured background.	Still unaffected, condition exceedingly good.

finish for steel chassis and similar items. For satisfactory performance, the plating must be sound. To this end, the work must be properly prepared, the plating process controlled to give adherent, stress-free coatings, deposits that are clean and free from included or co-plated impurities, and deposits of adequate thickness. Under these conditions, chromate passivation adds serviceability to the coating out of all proportion to the small effort and cost in its application.

Science and the Public Welfare

A CONFERENCE has been arranged under the title of, "Science and the Public Welfare" and will be held at the City Memorial Hall, Sheffield, on the afternoons of Saturday and Sunday, November 16th and 17th, 1946.

Many internationally known scientists are to address the conference and most aspects of scientific work will be represented. Professor P. M. S. Blackett, F.R.S., of Manchester University and Professor J. D. Bernal, F.R.S., of London University, will speak on the social implications of science. It is hoped that a representative of H.M. Government will address one of the sessions, while several foreign scientists are expected to take part.

Dr. J. Rotblat who is Director of Atomic Research at Liverpool University is to address the conference on, "The Future Use of Atomic Energy." There will also be speakers who are working in the Public Health Services, while Captain T. W. Barnard, O.B.E., of the Radiotherapy Centre will speak on the work of that institution. Medical scientists will give some indication of progress in Medicine and Surgery.

The conference is being organised by the North East Area Committee of the Association of Scientific Workers, 25, Change Alley, Sheffield, 1.

Symposium on the Failure of Metals by Fatigue

A SYMPOSIUM, in five sessions, on the failure of metals by fatigue will be held under the auspices of the Faculty of Engineering, University of Melbourne, Australia, in a week between November 18 and December 13, 1946. Papers to be presented for discussion are: "The Failure of Metals by Fatigue," by J. Neill Greenwood; "Metallography, Fatigue of Metals, and Conventional Stress Analysis," by H. F. Moore; "Theories of the Mechanism of Fatigue Failures," by W. Boas; "Fatigue Problems Associated with Aircraft Materials," by H. Sutton; "The Factors Contributing to Fatigue Failure in Aircraft," by C. W. George, S. F. Grover and B. Chalmers; "Repeated Loading on Structures," by A. G. Pugsley; "Structures Liable to Fatigue Failure and Some Considerations in their Design," by the Staff of the Battelle Memorial Institute; "The Electro-Chemistry of Corrosion-Fatigue," by W. R. Evans; "The Detection of Fatigue Cracks," by C. W. Orr; "The Measurement of Dynamic Strain," by F. W. Hooton; "Methods of Investigating the Fatigue Properties of Metals," by W. W. Johnstone; "Determination of Stress Concentration Factors," by F. S. Shaw; "Photo-Elasticity and Stress Concentration," by W. H. H. Gibson; "Fatigue Tests on Four Welded H-Beams," by A. L. Percival and R. Weck; "Residual Stresses, Their Measurement and Their Effects on Structural Parts," by G. Sachs; "The Design of Cylindrical Shafts Subjected to Fluctuating Loading," by G. G. McDonald; "Fatigue of Bolts and Studs," by J. G. Ritchie; "The Fatigue of Welded Steel Tubing in Aircraft Structures," by C. J. Osborn; "Notch Sensitivity of Metals," by M. S. Paterson; "Composition and Physical Properties of Steel in Relation to Fatigue," by D. O. Morris; "Conditions Leading to Fatigue Failure in Sleeve Bearings," by R. W. K. Honeycombe; "Fatigue Problems in the Gas Turbine Aero Engine," by A. R. Edwards; "The Prevention of Fatigue Failures in Metal Parts by Shot Peeling," by J. G. Brookman and L. Kiddle; "Failure of Railway Material by Fatigue," by H. O'Neill; "The Effect of Press Fits on the Endurance Limit of Axles and Crank Pins," by G. W. C. Hirst; "Fatigue Failure of Axles of Car and Wagon Railway Rolling Stock," by E. Connor; "Some Practical Aspects of Wire Fatigue in Aerial Telephone Lines," by D. O'Donnell and A. S. Bundle; "The Vibration of Telephone Line Wires," by H. C. Levey and P. R. Brett; "Fatigue Failures of Lead Telephone Cable Sheathing" by S. D. Chivers.

The papers will be printed and distributed to subscribers before the meeting. Spoken and written contributions to the discussion are invited. The subscription rate before the Symposium is £1 5s., which includes the right to receive a full set of advance copies, attendance at the meeting, and a copy of the bound volume. Extra copies of the volume can be ordered before the meeting at the advance copy rate of £1 1s. The charge for volumes ordered after the meeting will be £2 2s.

Enquiries and orders should be addressed to Professor J. Neill Greenwood, Research School of Metallurgy, The University, Melbourne, Australia.

The Iron and Steel Institute

THE autumn meeting of the above Institute will be held in the Lecture Theatre of The Institution of Civil Engineers, on November 13 and 14, 1946, at which, in addition to official business, the following papers will be presented for discussion:

Morning Session, November 13: "The Influence of Port Design on Open-Hearth Furnace Flames," by J. H. Chesters and M. W. Thring; "A Heat-Flow Meter for Use in Furnaces," by R. H. Baulk and M. W. Thring; an Introductory Address on "The Purpose and Plan of the Experiments," by J. H. Chesters, based on parts of Special Report No. 37; "Special Instruments and Technique," based on parts of Special Report, No. 37 and on the paper by R. H. Baulk and M. W. Thring.

Afternoon Session: "Thermal Conditions within the Open Hearth Furnace," based on Section II, Parts 10-14, and Section III, Parts 2 of Special Report No. 37; introduced by M. W. Thring. "General Conclusions," based on Section II, Part 9, and Section III, Parts 1 and 2, of Special Report No. 37; Mr. W. Geary will act as rapporteur.

Film Display: A programme of films has been arranged for the evening of November 13 (8 p.m. to 9.30 p.m.) to include: "Open-Hearth Furnace Flames"; "The Control and Prevention of Distortion in Arc Welding"; "A Photographic Investigation of the Brightness of Liquid Steel Streams"; and "The Measurement of Liquid Steel Temperatures."

Morning Session, November 14: "The Origin and Constitution of Certain Non-Metallic Inclusions in Steel," by J. R. Rait and H. W. Pinder; "The Neutralisation of Sulphur in Cast Iron by Various Alloying Elements," by H. Morrogh; "The Removal of Hydrogen from Steel."

Afternoon Session: "The New Annealing Plant for Steel Strip in Coils at the Whitehead Iron and Steel Co., Ltd., Newport, Mon.," by B. Jones and I. Jenkins; Joint Discussion on "The Protection of Iron and Steel Against Marine Corrosion and Fouling," based on the following three papers: "The Formulation of Anti-Corrosive Compositions for Ships' Bottoms and Under-Water Service on Steels.—Part II," by F. Fancutt and J. C. Hudson; "Report on Anti-Fouling Research, 1942-44," by The Marine Corrosion Sub-Committee; "Interim Descriptive Statement on the 'Leaching-Rate Test' for Ships' Anti-Fouling Compositions."

New Swedish Plant for Electro-Pig Iron

A THIRD electro-iron furnace has just been put into operation at the big State-owned iron works "Norrbottens Jernverk," in the north of Sweden. Through this extension, the plant's annual production capacity of electro-pig iron is likely to increase to 100,000 tons.

The "Norrbottens Jernverk," which was built during the war in order to step up the production of domestic iron and to increase the permanent labour facilities in this part of the country, has gradually been extended. The first electro-iron furnace was put into operation at the end of 1943 and the second some months later. This ironworks is using phosphorous ore from the Lapland mines.

Some Aspects of Nitriding

By S. A. J. Sage

"Degrease, box up, and nitride for 72 hours." The instructions are so clear, so definite and decisive that one cannot visualise any possible deviation or mistake being made. According to the instructions every component has no chance of being anything but a perfect one. But it is only by trying to adhere to instructions composed after much experimenting and many failures, that any components can be successfully treated. This article is written with the intention of showing how variations in the finished component can occur notwithstanding the fact that every attempt has been made to follow the instructions.

THE basis of the nitriding process is the fact that if ammonia is passed over steel heated to a definite temperature it reacts with the steel to form nascent nitrogen and hydrogen. It is the nascent nitrogen which is the hardening agent; tests have been carried out which show that molecular nitrogen is ineffective as a hardening medium. All steels can be nitrided but only a few can be hardened by this process. This is because the nascent nitrogen must be retained at or near the surface of the steel and not diffused wholly into the core if any hardening is to be obtained. Armco iron and mild steel will show a rise in nitrogen content throughout the material but the surface will not have hardened. It is only when alloy additions, mainly chromium and aluminium, are added to the basic steel that the rate of diffusion of the nitrogen into the steel is faster than the rate of diffusion through the steel, that hardened surfaces occur. It is, therefore, essential that the steel being treated is one that has the above characteristics of retaining the nitrogen at or near the surface.

The steels normally used for nitriding are those of the chromium-aluminium Nitralloy type (D.T.D. 87, 306, 317), the nickel-chromium molybdenum type (D.T.D. 228), the chromium-molybdenum "Hykro" type, and the austenitic nickel-chromium type (D.T.D. 49B).

With the exception of the austenitic steels which are used in the normalised condition the steels are usually delivered in the fully heat-treated condition, hardened and tempered to have a sorbitic structure. In this condition the steel has the best all-round properties of strength and ductility. That the steels can be fully heat-treated is due to the fact that the nitriding operation is invariably carried out at a lower temperature than that employed in tempering. It is one of the advantages of the process that the nitriding operation needs no high temperature treatment and that scaling with its attendant problems is avoided. Distortion and growth, however, can occur during the treatment and must be controlled otherwise interference may occur during assembly of finished components.

The crystal size of the steels should be as small as possible to obtain the best results on nitriding. The effect of crystal size on D.T.D. 87 especially is important as was well shown in one instance where the components were made from small forgings. Many components from one batch of nitrided work, but of two deliveries of forgings, were found to be "soft"—i.e., they only gave hardness values of the order of 800 V.P. No. as against the normal 1,000 V.P. No.

Micro-examination showed that the soft components were always associated with large grain size. The variation in structure can be seen from Figs. 1 and 2. The



Fig. 1.—Fine sorbitic structure of D.T.D. 87 which gave satisfactory hardness figures. $\times 100$.

Fig. 2.—Coarse-grained structure of D.T.D. 87 which gave poor figures. $\times 100$.

fine grained components invariably gave a case depth of 0.020–0.030 after 90 hours at 495°C., whilst the large grained components only gave 0.010–0.015 after similar treatment. This trouble was overcome by the suppliers modifying their forging technique to obtain a finer grained micro-structure.

Another problem emphasising the necessity for removing all decarburised metal from the surface of forgings was instanced when the sharp edges of many carburettor cam tracks started to crack and flake off after nitriding. The cams were made from forgings in D.T.D. 87 material and due to a variation in size one edge of the cam track had not been sufficiently machined to entirely remove all the decarburised surface. Fig. 3 shows the flaked edge of the cam and Figs. 4 and 5 show the massive micro-structure at the decarburised edge after nitriding. The structure was checked against that of a forging prior to nitriding and it was found that either the nitriding or the time at nitriding temperature had caused the grain growth of the almost carbon free crystals. The flaking had occurred along the cleavage planes as shown in Fig. 4. The core hardness and the case hardness away from the defective area was satisfactory. This trouble was overcome by tightening the tolerances of forging size and maintaining correct positioning of the forgings during primary machining operations. This made certain that all surfaces were adequately machined and all decarburised areas removed.

Whilst still discussing the effect of the steel on the nitriding operation another phenomenon noticed during



Fig. 3.—Cracking on the edge of small cam made from D.T.D. 87. $\times 5$.

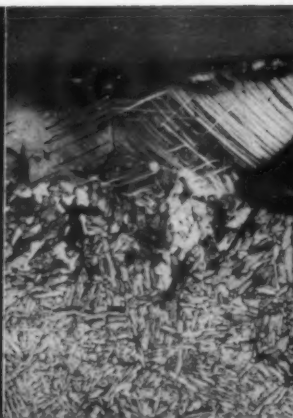


Fig. 4.—The coarse grains and cleavage planes of nitrided decarburised areas. $\times 50$.



Fig. 5.—Large decarburised crystals in D.T.D. 87. $\times 100$.

a period of operations should be mentioned. Many components made from D.T.D. 228 were found to be pitted badly after the nitriding operation. The hardness of the case and core was tested and found to be satisfactory and the depth of case was within acceptance limits. Analysis conformed to specification. Micro-sections across several pits showed that in every case an inclusion of manganese sulphide was situated at the bottom of the pit. The general appearance of the pit and inclusions was similar to that shown in Figs. 6 and 7. The sections gave an average inclusion count of 90 which was much higher than that normally found. No theory was advanced as to the effect of the inclusions on the spalling but it was found that the pitting phenomenon was overcome by using steel which was free from inclusions. Check tests on many components free from pitting gave inclusion counts of under 40. The steel used in the above components was either electric or acid open-hearth type which is normally very clean. No reason was found for the abnormal dirty cast of steel.

Stopping Off

When it has been decided that only certain areas of a component are to be hardened, the other areas must be "stopped off."

Unlike carburising in which metal can be removed during the various operations of the process to leave soft areas in the finished component, nitriding does not allow this and all stopping off must be done prior to the operation of hardening. This is done by applying a medium to the steel which resists the action of the nitrogen. Such media now in use are solder, electro-deposited tin or nickel and tin-plating by dipping. This instruction of stopping off may involve many problems because it is necessary for many components to stop off the stopping off medium. Consider that solder or tin is going to be used. All parts to be hardened must then be coated with whitening so that the tin and solder do not encroach on the parts to be hardened. After the component has been dipped in the molten metal the whitening is removed and the component made ready for nitriding. If electro-deposited tin or nickel is used a lacquer is painted on those portions to be hardened so that the plating only adheres to those parts where the

soft areas will be. The common trouble met with in whitening and lacquering is that if grease or finger-prints occur the covering does not adhere properly and the tin or electro-deposited coating penetrates the lacquer and soft spots are found on the finished components where hard areas are needed. Cleanliness is essential.

In the case of valves made from austenitic D.T.D. 49B a special sequence of operations is used. It has been found that a coating of copper is essential in nitriding this type of steel—it acts as a catalyst. The valve is first copper-plated all over and then those parts which are to be left soft, usually the head and tip, are nickel-plated. The stem, copper-coated, is either lacquered or stopped off with insulation tape whilst the remainder of the valve is being nickel-plated. Troubles are often found when the nickel solution penetrates the lacquer to give soft spots on the finished stem. Lacquers used for stopping off must be carefully removed after plating, otherwise soft streaks or areas are found on the valve where hard areas are specified.

Stabilising

Ferritic steels are given a stabilising treatment prior to nitriding to remove machining stresses set up in the primary operations. This is normally a straightforward operation and if the controlling mechanism of the furnace is working correctly no troubles are experienced.

One case of soft spots on hardened parts was found which was associated with the stabilising operation. The components had been stabilised, then tin-plated and finally ground on the portions to be hardened. During the nitriding operation the tin melted and ran on to the portions to be hardened, causing soft areas. This was overcome by reversing the sequence of operations to:—



Fig. 6.—Pitting of the surface of D.T.D. 228 material due to inclusions in the steel. $\times 10$.



Fig. 7.—A large inclusion at the bottom of one of the pits. $\times 250$.

- Tin-plating.
- Stabilising.
- Final grinding.

The appearance of the component after plating and stabilising is not attractive, the bright tin-plating having changed to a dirty brown. However, the thin film of FeSn compound formed at the interface of the plating and the steel is still effective for stopping off the action of the ammonia. All melting of the tin occurred in the stabilising operation and no trouble was experienced when the new procedure was followed.

After stabilising all components are degreased, preferably in a trichlorethylene degreasing unit and transferred to the container of the nitriding furnace.

Finger-prints always cause trouble either giving rusty marks or soft spots on the finished component. It is, therefore, essential to avoid handling components after degreasing. If the components are small they can usually be hung on wires or rods, whilst if they are large lifting tackle is used which goes through the same degreasing operation as the component.

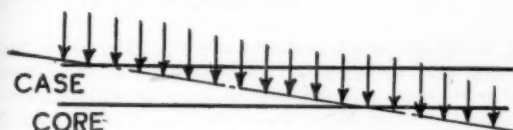


Fig. 8.—Taking hardness values on a gradient at intervals of $\frac{1}{16}$ in.

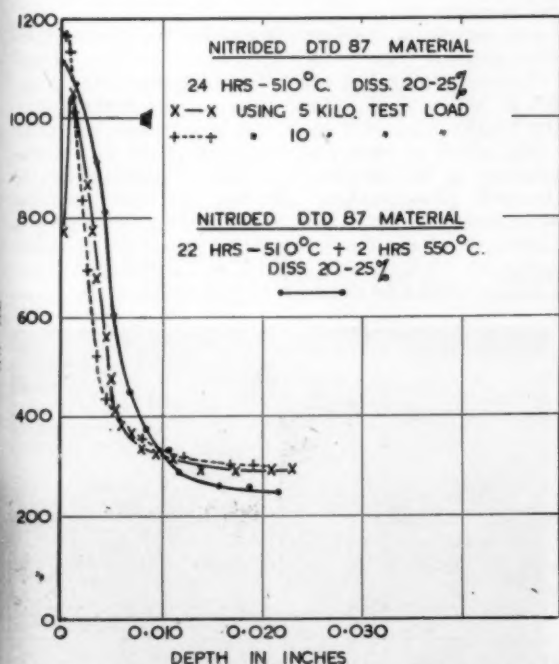


Fig. 9.—Graph showing effect of nitriding D.T.D. 87 at different times and temperatures.

The Nitriding Operation

This is carried out in a specially designed and equipped furnace which consists essentially of a sealed container into which the components are packed, surrounded by heating elements. The ammonia, usually stored in cylinders, passes from the control pipettes through the

container, reacts with the steel components and is exhausted into the air as far away from the furnace as convenient.

Very few troubles originate in the furnace—those which do occur being due to the failure of the control mechanism for the heating arrangements, the flow of ammonia or the failure of the sealing devices. If the thermocouples fail the normal action of the control mechanism is to switch to full power which instantly raises the temperature of the furnace. This formerly burnt out the heating elements of the furnace but safety devices are now generally incorporated either in the form of a gold thermocouple which melts and cuts the current as the temperature of the furnace rises, or a special circuit in the control instruments. It is always advisable to change thermocouples every fortnight to avoid failures.

One instance in which a load of parts was scrapped was due to the use of a thermocouple which touched the end of the sheath. This gave an untrue reading of the temperature of the furnace due to the introduction of a third junction. Therefore, the thermocouples should be checked for length against their own sheaths and the sheaths on the container.

The normal procedure of nitriding is to load the furnace and seal the joints. The ammonia is admitted to the container and the air is swept out. When this has been accomplished—it takes several hours on large installations—the heating is switched on and the ammonia flow is then balanced as the temperature rises to give a dissociation value of approximately 30%. As the temperature rises the flow will have to be increased to maintain this figure, but tests should be taken every quarter of an hour.

The temperature of nitriding and dissociation varies with the steel, the Nitralloy type being treated at 495°C. and 20/25% diss., D.T.D. 228 at 510°C. and 30% diss., and D.T.D. 49B at 610°C. and 35/45% diss.

After nitriding for that time necessary to give the required depth of case, the heat is switched off and the furnace allowed to cool to 300°C. in the case of D.T.D. 49B or 150°C. for the ferritic steels, the ammonia still being admitted. When this temperature is reached the ammonia is switched off and the furnace is opened. If the container is opened before this temperature is reached all the components are highly coloured and may be softened slightly due to oxidation and/or tempering of the case.

The ammonia gas must pass through the container fast enough to sweep out any hydrogen formed, but the flow is not so critical once the hardening operation has started. The hydrogen, if allowed to collect, stops any hardening and will effectively de-nitride and soften any surfaces which have previously been hardened. Fans made of heat-resisting steel are usually fitted to avoid any hydrogen pockets. If ammonia is passed too fast no advantage occurs, ammonia is wasted and the components near the inlet ports of the container are frequently cooled below the nitriding temperature. Recent work in America and work on installations in England suggests that the majority of plants could decrease the flow of ammonia after the first ten hours without any ill effects to the charge.

If the seal of the container fails—it is usually of finely-ground chrome ore or solder—the escape of ammonia which is at a slight pressure in the container due to the back pressure of the exhaust system, usually

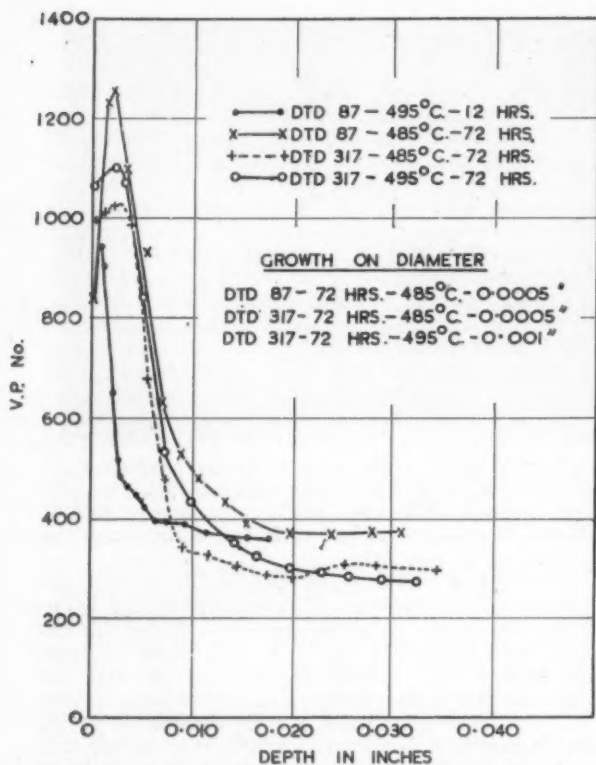


Fig. 10.—Graph showing growth due to nitriding D.T.D. 317 and D.T.D. 87 at different times and temperatures.

makes the proximity of the furnace very uninhabitable. No detrimental effects occur to the components being nitrided although during the cooling down air is often drawn into the container with subsequent colouring of the components. This film is removed by the polishing operation which is normally given to nitrided components to remove the thin matt film which has formed during the operation.

The Nitrided Surface

Except under abnormal circumstances this is rarely examined. In the normal course of events when the component is unloaded from the container, it is polished and hardness tested. If it is satisfactory, that is to say, if it gives a hardness reading above the minimum requirements, it is accepted and passes out into the world to carry out its intended work.

Occasionally components pass all the tests in the works but fail to carry out their normal duties. Sometimes the nitrided skin flakes off or wears badly, others showing no wear under the same circumstances. When this happens, an examination of the nitrided layer by either a gradient hardness test or by a metallurgical examination may give the reason for the abnormality.

A gradient hardness test, easily carried out on a test piece, but often with difficulty on a small component, consists of grinding a taper gradient from the surface to the core of the component. An angle of 5-10° ensures that even with a thin case several hardness readings can be taken from which a suitable graph can be drawn to show up any abnormalities. The readings should be taken at approximately $\frac{1}{8}$ in. intervals as shown in

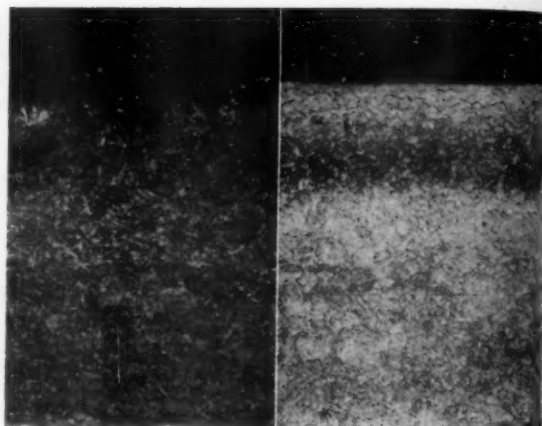


Fig. 11.—Nitrided D.T.D. 87 after 36 hours at 485°C. $\times 100$. Fig. 12.—Nitrided D.T.D. 228 after similar treatment to that of Fig. 11. $\times 100$.

Fig. 8. From these, either by trigonometry or by direct reading with a ball-ended micrometer, can be obtained the hardness at any determined depth from the surface. Graphs similar to those shown in Figs. 9 and 10 for the two materials D.T.D. 87 and D.T.D. 317 are obtained. These show the hardness curves obtained from test specimens which were given varying treatment of time and temperature.

The growth on the diameters under the above conditions were:—

D.T.D. 87, treated at 485°C. for 72 hours, 0.0005
 D.T.D. 317 " " 485°C. for " 0.0005
 D.T.D. 317 " " 495°C. for " 0.001

The effect of time and temperature on the micro-structure of the nitrided layer can be assessed by the attached photographs. At the specified nitriding temperature of 485°C. for 36 hours, D.T.D. 87 gives a case depth of approximately 0.006/0.010 in. as shown in Fig. 11. D.T.D. 228 for the same time at 510°C. has a case of similar depth but of slightly different structure

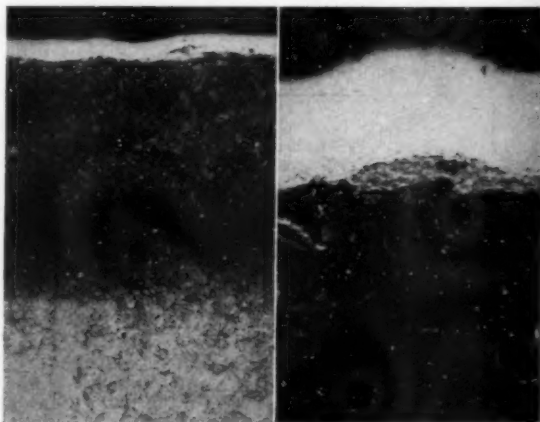


Fig. 13.—Nitrided D.T.D. 228 after 2 hours at 650°C. Hardness approximately 700 V.P. No. $\times 100$.

Fig. 14.—As for Fig. 13 but at a higher magnification. Shows the intermediate product between the excess nitride layer and the normal hardened zone. $\times 350$.

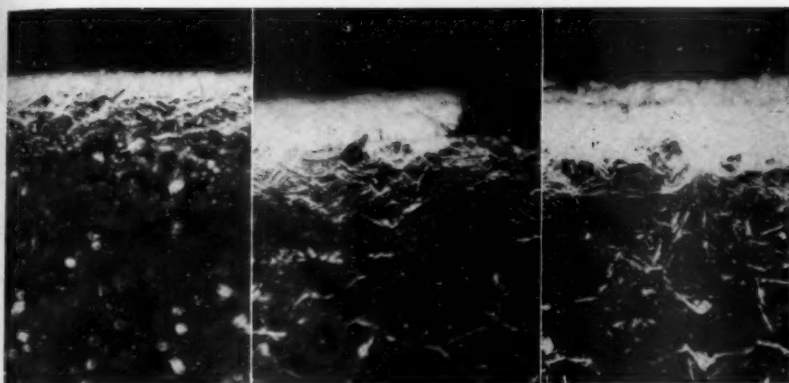


Fig. 15.—Nitrided D.T.D. 87. First formation of the brittle case at 510° C. for 10 hours. $\times 350$.

Fig. 16.—Nitrided D.T.D. 87. Thicker and more brittle case formed at 550° C. for 10 hours. $\times 350$.

Fig. 17.—Nitrided D.T.D. 87. Formation of outer layer on excess nitride layer at 630° C. for 2 hours. $\times 350$.

as shown in Fig. 12. It was found that at 485° C. the depth of case obtained on D.T.D. 87 increased at the following rate:—

Case Depth	Time at Temperature
0.005/0.010 in. 36 hours
0.015/0.020 in. 72 hours
0.020/0.025 in. 90 hours

Due to the fact that the nitride layer under some conditions has unusual qualities, tests were made to produce abnormal layers by varying the treatments.

Fig. 13 shows an excess nitride layer on D.T.D. 228 after treatment at 650° C. for 2 hours. Whilst this

temperature is far higher than that normally used, it illustrates the structure which is sometimes found at the surface of cylinder liners which have failed due to "picking up and scuffing." The white layer, which is higher in nitrogen than the normal nitrided case, is very hard and brittle. Hardness tests on this outer layer gave unsatisfactory results as the impressions "spall," but scratch tests show that it is above 1,100 V.P. No. Fig. 14, at a higher magnification, shows the structure of the white layer and how an intermediate product has formed between it and the normal case.

D.T.D. 87 was treated at various temperatures to

obtain the excess nitride layer. Figs. 15, 16 and 17 show how the layer first formed at 510° C. for 10 hours becomes more pronounced at 550° C. and at 630° C. for 2 hours formed an outer zone in the excess layer. No analyses were taken as to nitrogen content and hardness tests were difficult due to spalling but in every instance the outer layer was the hardest and most brittle.

From the above discourse, it can be seen that variations can and do occur in a process which is normally given very strict supervision. It is only by the study of the components which have given abnormal results that a higher percentage of good components can be produced and the correct properties obtained.

Experimental Stress Analysis Group

A MEETING was held at University College, London, recently, with the Provost, Dr. D. R. Pye in the Chair and some sixty persons from academic, government and industrial research establishments present to discuss the formation of a society concerning itself with photoelasticity. It was decided to extend the scope to other techniques of experimental stress analysis and to form an informal group whose object will be the interchange of knowledge and experience among its members. Some of the research workers had suggested that the group should be part of the Institute of Physics rather than form a new Society. The Secretary of the Institute, who was present by invitation, stated that his Board was always prepared to give sympathetic consideration to requests from informal groups interested in Applied Physics, for a little assistance in the inaugural period, and that this could be accepted without prejudice to the ultimate decision. It was, therefore, agreed to leave the constitution open for the present and in the meantime to make a formal request to the Institute for temporary assistance.

Col. H. T. Jessop (University College, London) was

elected Chairman of the group, and Mr. E. K. Frankl (Engineering Department, University of Cambridge) Honorary Secretary. The following were elected to the Committee: Mr. W. A. P. Fisher (R.A.E., Farnborough), Mr. R. G. Manley (Vickers Armstrong, Ltd., Newcastle-on-Tyne), Mr. C. W. Newberry (L.M.S. Railway, Research Dept., Derby), Dr. S. C. Redshaw (Boulton Paul Aircraft Co., Wolverhampton), Mr. D. G. Sopwith (Engineering Div., N.P.L., Teddington), Dr. J. Ward, (Huddersfield Tech. College).

The Committee was instructed to:—

1. Widen the circle of membership by contacting research workers in all fields of experimental stress analysis.
2. Make arrangements for a meeting within 12 months at which papers shall be read and the future constitution of the group shall be decided.
3. To prepare and circulate bulletins of information which may be of interest to members.

Any research workers or others who are interested in experimental stress analysis are invited to communicate with the Honorary Secretary, Mr. E. K. Frankl, Engineering Laboratory, Cambridge.

Ductility of Metals and Alloys used in Construction-II

The Effects of Notching under Axial and Eccentric Loads

By Dr. Georges Welter

Ecole Polytechnique, Montreal

This paper records and discusses results of tests made on construction materials in order to establish a classification, with respect to their ductility, of light metals and alloys in comparison with other heavy structural materials. The effect of notching under axial and eccentric loads has also been investigated. For this purpose, standard and special notched specimens were tested under axial and eccentric loads producing single tension as well as combined tension and bending stresses.

Eccentricities up to $\frac{1}{8}$ in. seem to have no harmful influence on standard specimens of mild steels while light alloys and brass are not ductile enough to stand these critical conditions. In specially brittle material such as cast iron there appeared to be a closer relationship between the ultimate strength and the degree of eccentric loading.

Similar results were obtained with conical specimens which provided a better differentiation amongst materials of different degrees of ductility.

Stress-strain curves of commercial metals and alloys in the "as-received" as well as in the "cold-stretched" and the "annealed" conditions, and tested under various eccentricities, give interesting information regarding the ductility of these materials. The energy absorbed during the loading process also permits a certain evaluation of the materials with regard to their strength and ductility. These diagrams show that for eccentrically loaded notched specimens, very ductile materials lose little of their properties as compared with axial loading, while less ductile and brittle materials lose rapidly their ultimate resistance and stand very small amounts of energy; these characteristics provide a useful index for the evaluation of strength and ductility. Nickel-copper and nickel-iron alloys are, in this respect, outstanding and far superior to light alloys.

A certain classification is given based on various indices for ductility and strength properties of notched, axially and eccentrically loaded specimens.

Discussion of Results

(1a) Load-deflection diagrams of Standard and Notched Specimens Under Axial Loads and for Various Conditions of the Metal

THE basic stress-strain diagrams recorded by the tensile machine for standard cylindrical specimens of the material in the "as-received" condition are reproduced in Fig. 10, while the diagrams for the "cold-stretched" and "annealed" materials appear in Fig. 11. The maximum rise of these curves indicates the ultimate strength and the elongation is represented by the maximum horizontal distance. It is evident that these curves, being automatically recorded by the machine, do not represent in abscissae the real values of the modulus of elasticity of the materials; in addition to the elastic deformation of the gauge length of the specimens, the abscissa

also includes the deformation of the total length as well as that of the grips, the cross-heads and the whole frame of the testing machine. Plotted to the same scale, however, these curves already give at first glance a fairly good idea of the co-relation between high tensile strength and ductility (deformation) of the various structural materials tested. Some characteristic results shown in these curves, such as the ultimate strength, the yield point measured by the stress-strain record, the elongation, the reduction of area and the total energy necessary to break the specimen are illustrated in order of increasing strength in Fig. 12 for materials in the "as-received" condition. For the discussion of results, the materials have been divided into three groups. According to the chart in Fig. 12, the special steels rank, with Monel metal, among group III showing the highest tensile strength. Armco iron, nickel, mild steel I and II, brass, duralumin and magnesium alloy I and II, take an intermediate rank in Group II. At the left of the chart, in the first group,

are represented pure metals such as copper, zinc, aluminium and a few cast alloys. The metals in this group show, besides an exceptionally high reduction of area as, for instance, 90% for zinc, 72% for copper and 62% for aluminium, also a good elongation of 30% to 60%.

It is interesting to note that Monel metal, a non-ferrous alloy of the third group, occupies a good place with the high resisting steels. Monel K SB particularly shows outstanding mechanical properties. The high reduction of area of Monel RA, the highest of Groups II and III, is surpassed only by the extremely ductile zinc of the first group and is approached by that of copper in the same group. Also, the elongation of Monel metal RA is very good at 50% and is surpassed only by zinc (Group I) which shows the highest elongation of all metals in the three groups. The total energy absorbed is also very high for the materials in Group III; Monel metal K SA and SB, as well as stainless steel GA, rank highest, nearly equal with nickel in group II.

A similar method for testing notched bars of heat-treated low alloy steels has simultaneously been worked out by G. Sachs, J. D. Lubahn and L. J. Ebert, *Transactions A. S. M.*, Vol. XXXIII, p. 340, 1944.

Fig. 10.—Stress-strain records of standard cylindrical specimens of the material in the "as-received" condition.

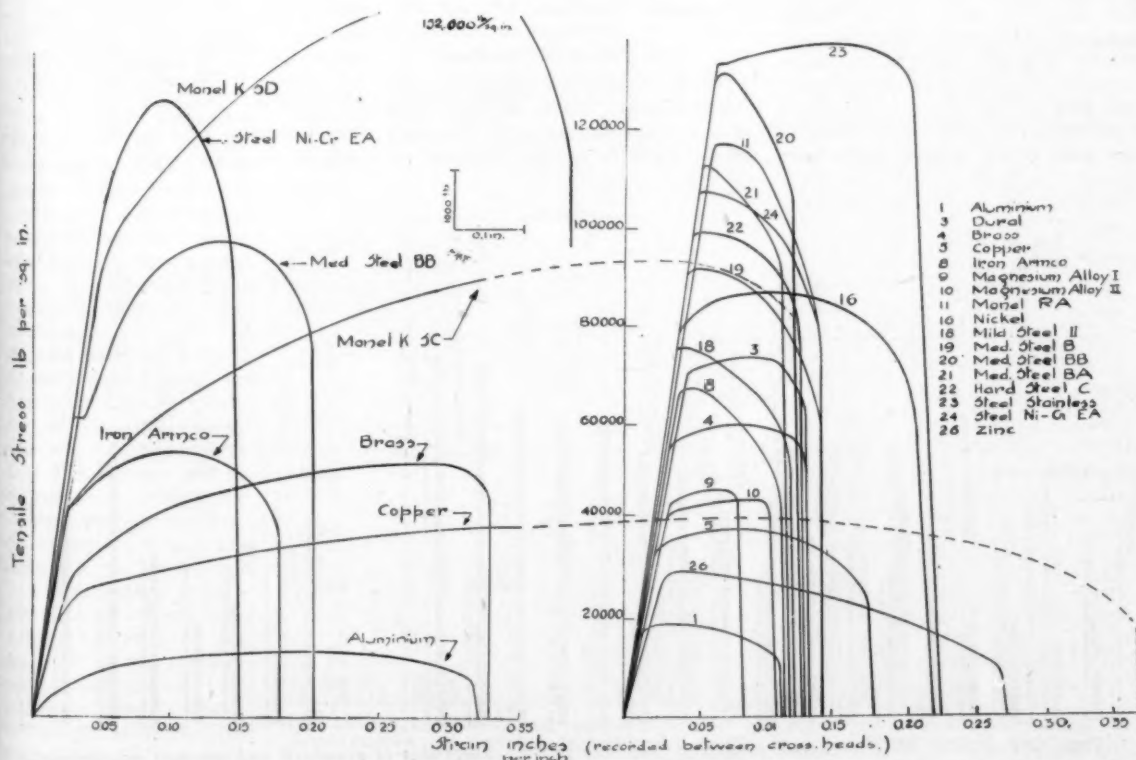
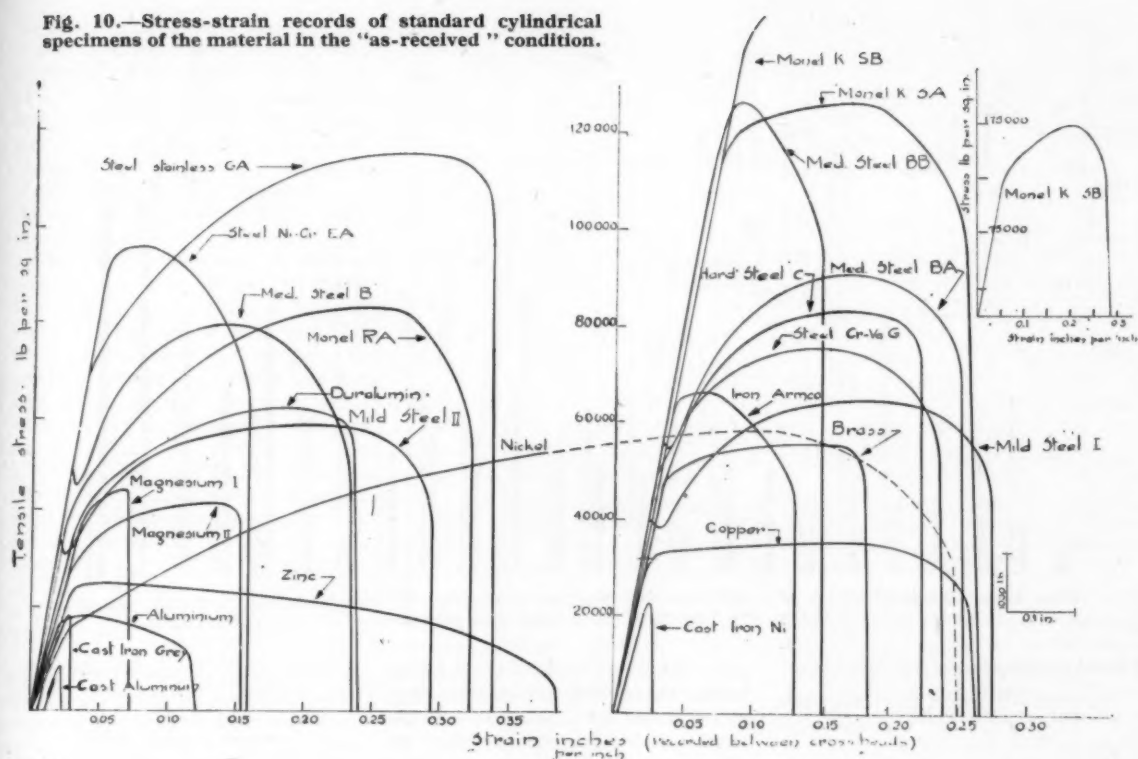


Fig. 11.—Stress-strain records of standard cylindrical specimens of the material in the "cold-stretched" and "annealed" condition.

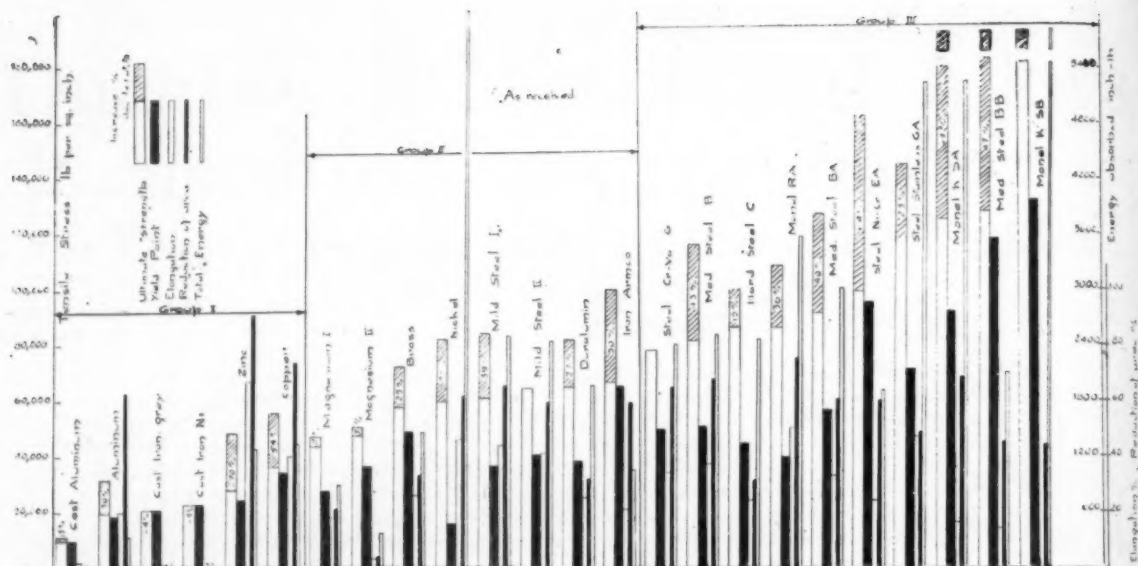


Fig. 12.—Characteristic results of load-deformation diagrams of standard and notched specimens under axial loads in the "as-received" condition in order of increasing strength.

(1b) Cold-stretched Material

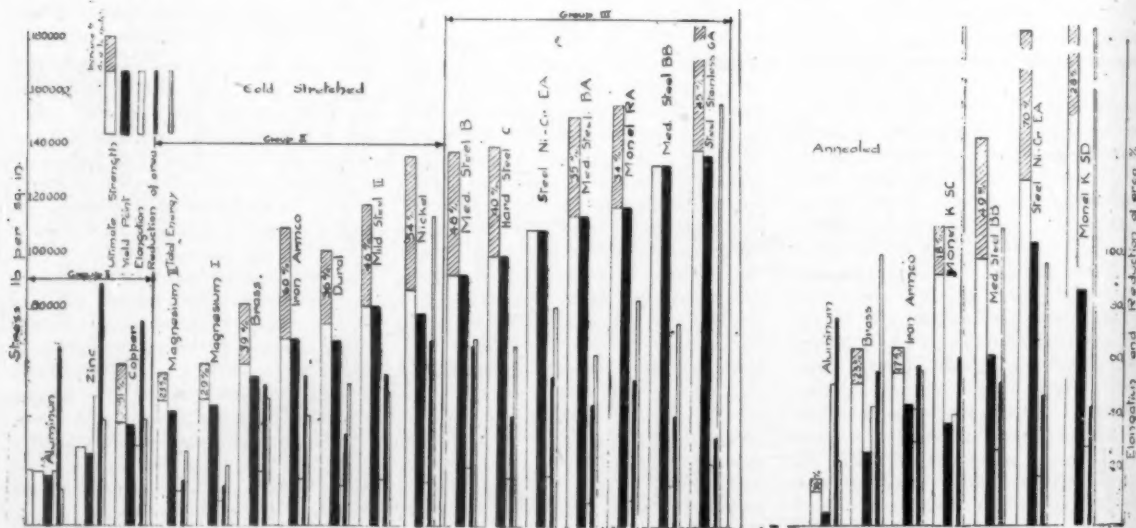
Stress-strain curves for tests made on specimens of cold-stretched materials are reproduced in Fig. 11. Plotting again the results in order of increasing resistance (Fig. 13), it is seen that the rank of the various metals is changed somewhat by comparison with Fig. 13. In the intermediate group, the positions of Armco iron and mild steel are interchanged with respect to duralumin, while in the third group similar shifts have

taken place for some of the special steels. As a result of cold-stretching, Monel metal RA now ranks with the highest resisting materials. Fig. 13a shows the tensile characteristics of some of the materials tested in the "annealed" condition.

(1c) Effect of Notches

As the effective increase in the tensile strength, due to the prevention of flow of the material by the notching effect, might be of some interest, the

materials were also tested with a sharp notch in the specimen. The increase in the ultimate stress is represented by the hatched portion of the column representing the maximum strength in Fig. 13. It will be seen from these results that, with material in the "as-received" condition, a notch in the specimen will, by preventing the flow of material, increase the strength generally from 20% to 40%. With cast alloys there is no increase, while the magnesium alloys show a very small



Figs. 13 and 13A.—Characteristic results of load deformation diagrams of standard and notched specimens under loads in the "cold-stretched" and "annealed" conditions in order of increasing strength.

percentage of increase. The strength of steel BB (cold-rolled) and of nickel-chrome steel has increased by 47% and 64% respectively. With pure metals, such as aluminium, copper, nickel, iron and zinc, the strength has increased from 50% to 72% as a result of notching in the test specimen.

Even with materials "cold-stretched" up to the maximum load, notching of the specimen caused an important increase in the strength. This is shown graphically in Fig. 13 where the increase is represented by the hatched portion in the column of maximum strength. Despite the fact that these materials had been cold-worked before testing, their strength was increased, as a result of notching in the specimen, by 23% to 45%, while in the case of copper, nickel and Armco iron, the increase ranged from 50% to 60%. With some of the materials tested in the "annealed" condition, the range of increase was even wider (e.g., Armco iron: only 17%; and Ni-Cr steel: 70%, Fig. 13a).

(2) Notched Cylindrical Specimens Loaded Under Increased Eccentricities

These tests were carried out on 22 materials in the "as-received" condition, on 13 of these materials cold-stretched before the notch was machined in the specimen, and on 8 materials in the annealed condition. The test results for some of the materials are shown separately in the form of single stress-strain curves in Figs. 14 and 14a. For each material, four tests were made: under axial load, under $\frac{1}{8}$ in., $\frac{1}{4}$ in. and $\frac{1}{2}$ in. eccentricities, and the tensile strength was plotted from the records of the testing machine. The stress-strain curves of ductile materials, such as copper and Armco, are nearly the same for axially or eccentrically loaded notched specimens (Fig. 14). The ultimate load for copper is practically unchanged even under eccentric loads of $\frac{1}{2}$ in., and strangely, for Armco iron it is even slightly increased; moreover, the total energy absorbed by the specimen at the breaking point (area beneath the stress-strain curve) is hardly changed under eccentric loads.

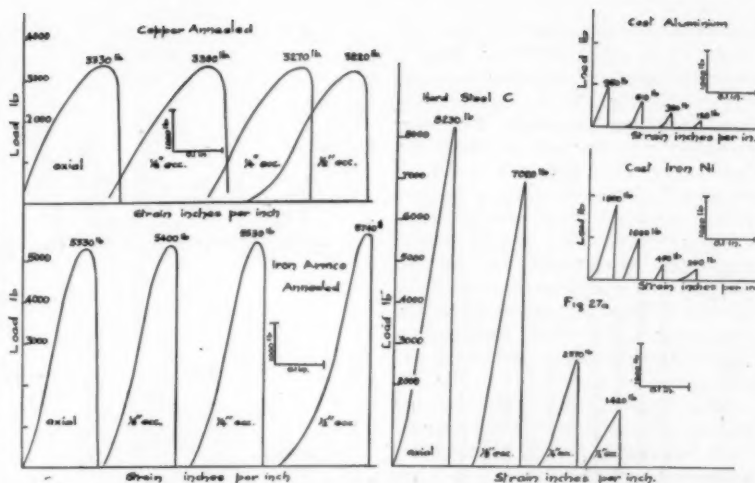


Fig. 14.—Stress-strain records of ductile notched specimens loaded axially and under increasing eccentricities.

Fig. 14a.—Stress-strain records of brittle notched specimens loaded axially and under increasing eccentricities.

On the other hand, however, less ductile materials behave in a completely different manner, giving, under axial loads and with increased eccentricities, very characteristic stress-strain curves (Fig. 14a). Not only the ultimate load decreases rapidly step by step to very low values, but the amount of energy necessary to break the specimen decreases sharply with increasing eccentricities. Very characteristic diagrams for hard steel, cast aluminium and grey cast iron have thus been recorded and are reproduced in Fig. 14a.

From those results it would seem that the amount of energy necessary to break a specimen tested under combined tension and bending stresses is a valuable characteristic for measuring the ductility and toughness factor of the material; this amount is influenced not only by the resistance but also by the plastic deformation of the material.

(2a) Results of Tests on Materials "as-received"

From the records of the machine as reproduced in Figs. 14 and 14a, the

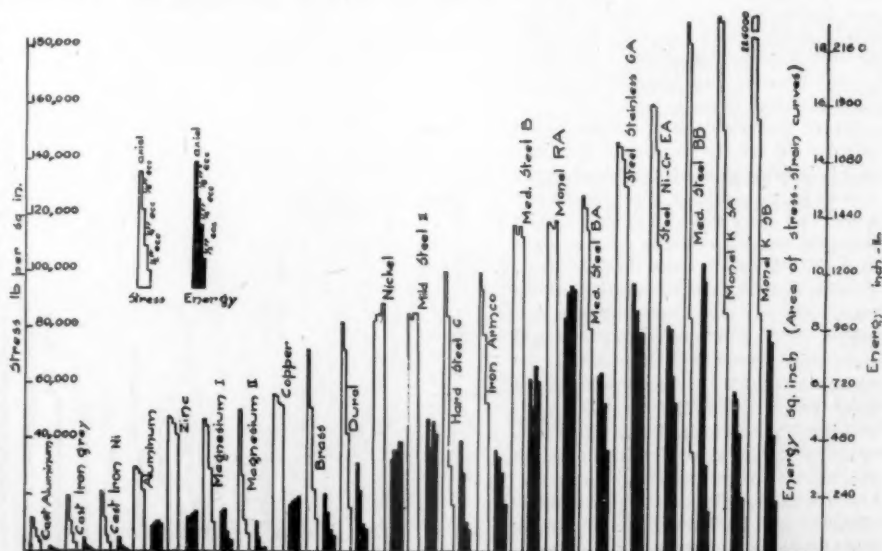


Fig. 15.—Stress and energy results of notched specimens loaded under increasing eccentricities; material "as-received," results in order of increasing breaking strength.

results of tests on material in the "as received" condition are shown graphically, in order of increasing breaking strength, in Fig. 15. On this diagram there are two symbols for each material: a hollow column where the four steps illustrate the breaking strength under axial, $\frac{1}{8}$ in., $\frac{1}{4}$ in. and $\frac{1}{2}$ in. eccentric loads respectively, starting from the left; a solid column where the energy absorbed by the specimens is similarly illustrated for the four different conditions of loading. Furthermore, all load deformation diagrams presenting a very characteristic shape are reproduced in Fig. 16.

At first sight, pronounced differences and variations can be observed between these test results. It will be seen that, with most materials, there is a sharp drop in the breaking strength (hollow column, Fig. 15) under eccentric loading as compared with axial loading. For instance, with cast iron alloys the load drops from 20,000 lb. per sq. in. and 21,700 lb. per sq. in. to 3,020 lb. per sq. in.; with magnesium alloy II, the load drops from 50,700 lb. per sq. in. to 6,580 lb. per sq. in., or 85%; for brass 84%; and for duralumin, 80%. Hard steel with 0.9% C. is also very brittle since the load drops from 99,400 lb. per sq. in. to 17,100 lb. per sq. in., or 83%.

On the other hand, however, there are materials whose resistance seems to be only slightly affected by eccentric loading. It can be seen from Figs. 15 and 16 that the drop in the breaking load between axially loaded specimens and those loaded under $\frac{1}{4}$ in. eccentricity does not exceed 20% for most of the following materials: zinc 14%, copper 6%, medium steel up to 37%, stainless steel 11%.

Other materials do not seem to be affected at all by eccentric loading, and it is astonishing to find that, even up to $\frac{1}{4}$ in. eccentricity, some specimens show a somewhat higher tensile strength than specimens of the same material tested under axial load. These surprising characteristics can be observed on the load deformation curves of Fig. 16 and it will be noted that this remarkable increase in the ultimate breaking strength takes place only with very ductile materials such as nickel, mild steel, Monel metal RA, and to some extent with medium steel B up to $\frac{1}{4}$ in. eccentricity.

With the brittle materials, the energy absorbed (solid column, Fig. 15) during the tensile tests decreases rapidly with increasing eccentricity; the specimens for all materials of this group show a

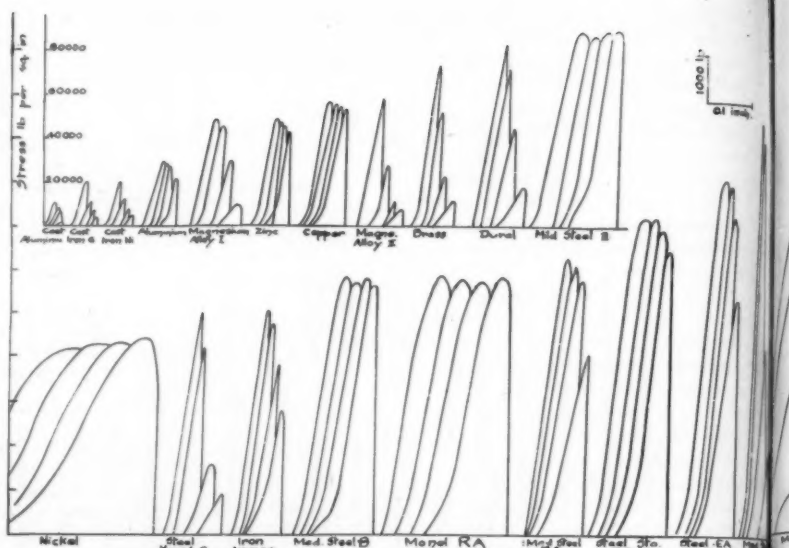


Fig. 16.—Characteristic load deformation diagrams of notched specimen material "as-received" side

very low degree of resistance under eccentric loading. All cast alloys are very typical in this respect as well as wrought magnesium alloys which could not stand even 50 in.-lb. with $\frac{1}{8}$ in. eccentricity (Fig. 15). Armco iron, brass, duralumin, hard steel, medium steel BB and Monel K withstood loads from 50 up to 250 in.-lbs.

Finally, other metals very characteristically showed increasing energy with increasing eccentricity. To this group belong the pure metals such as wrought aluminium, zinc, copper and

nickel, and only one high resistant alloy, Monel metal RA. To some extent, medium steel B, showing an increase in energy up to $\frac{1}{4}$ in. eccentricity, may also be considered as belonging to this group. All the other structural materials showed a tendency towards decreasing energy for increasing eccentricities.

Classifying the materials tested in the order of resistance at $\frac{1}{2}$ in. eccentricity (Fig. 17), it is seen that the rank of some of the metals has changed compared with the classification in

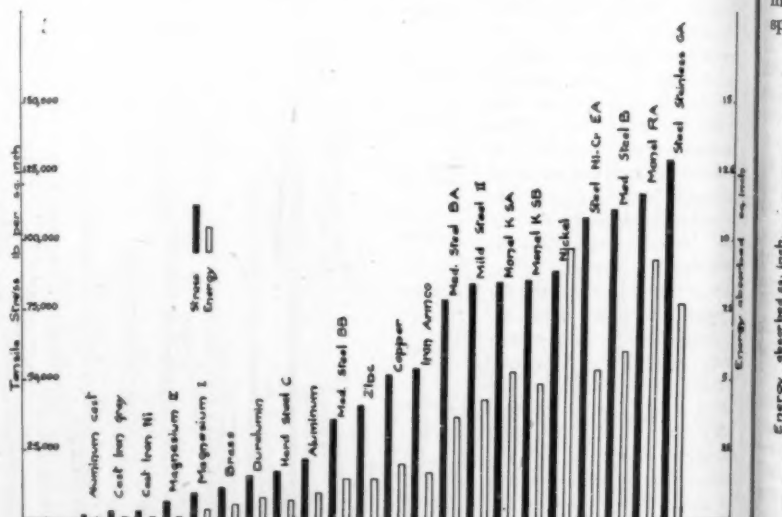


Fig. 17.—Classification of the materials at $\frac{1}{8}$ in. eccentricity in order of resistance of notched specimens.

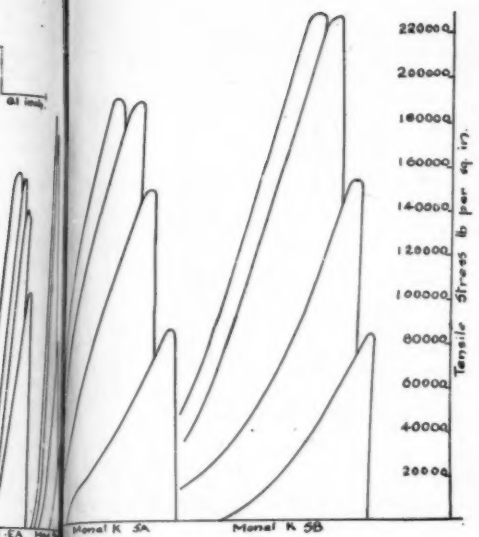


Fig. 15. In this new classification, the light metals and alloys, particularly the magnesium alloys and duralumin, occupy an inferior rank. Even when taking into consideration their density, they still appear very inferior compared to extremely ductile and tough materials such as Monel metal and some special steels. It looks as if the group of light metals will never fill the gap which exists in this respect, and that they will not even nearly reach the very high ductility combined with high resistance of the iron and nickel alloys, such as Monel metal, special steels, etc.

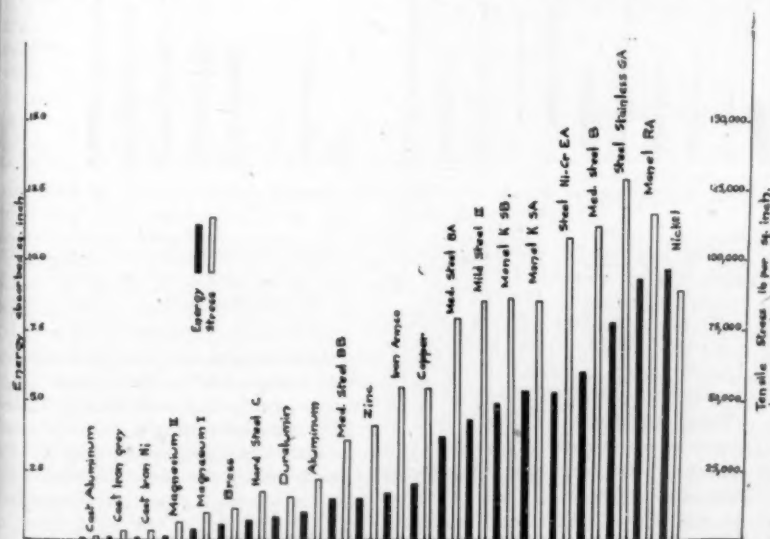


Fig. 18.—Classification of the materials at $\frac{1}{4}$ in. eccentricity in order of the energy absorbed by notched specimens.

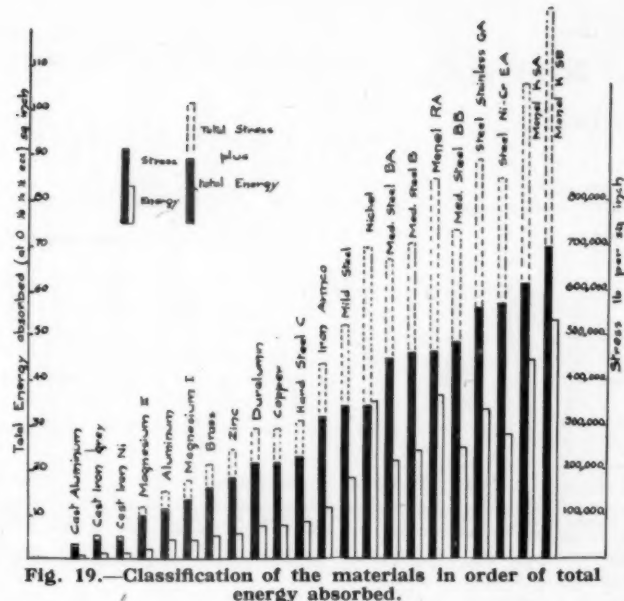


Fig. 19.—Classification of the materials in order of total energy absorbed.

Considering only the energy absorbed by the notched specimens under $\frac{1}{4}$ in. eccentric load (Fig. 18), a procedure which may give a better measure of the ductility of materials since their plastic deformation is involved in this value, we again find that Monel metal RA and special steels (such as stainless, medium and Ni-Cr) head the classification and that the light metals appear very inferior in this respect. Comparing, for instance, the results obtained for duralumin and magnesium alloy I with those of Monel metal, it is seen that the ratios of resistance are 1 to 11.8 and 1 to

23.5 respectively in favour of Monel. Taking into consideration the density, the ratios become 1 to $3\frac{1}{2}$ and 1 to 11, still an unfavourable relation for light alloys which probably cannot be much improved in the present state of metallurgical science.

If now we take as a standard of measure the total energy absorbed by measuring for each metal the total area under each of the four curves (0, $\frac{1}{4}$ in., $\frac{1}{2}$ in. and $\frac{3}{4}$ in. eccentricity), we obtain the classification illustrated in Fig. 19. Again it is seen that the light metals stand far from the position occupied by nickel and iron alloys. Magnesium II alloys, for instance, withstood only $\frac{1}{10}$ of the amount of energy absorbed by Monel metal.

(2b) Results of Tests on Cold-stretched and Annealed Materials

The stress-strain diagrams of these tests are reproduced in Figs. 20 and 21. It will be noted that the results are similar and even more characteristic than those of the preceding series of tests. Here again, the Monel metals and the special steels lead the entire group of materials. It can be seen that in general the breaking strengths are all high and the energy absorbed has in some cases somewhat decreased as a result of cold-stretching. The property of decreasing breaking strength with increasing eccentricity in some of the materials is even much more pronounced than in the preceding series of tests.

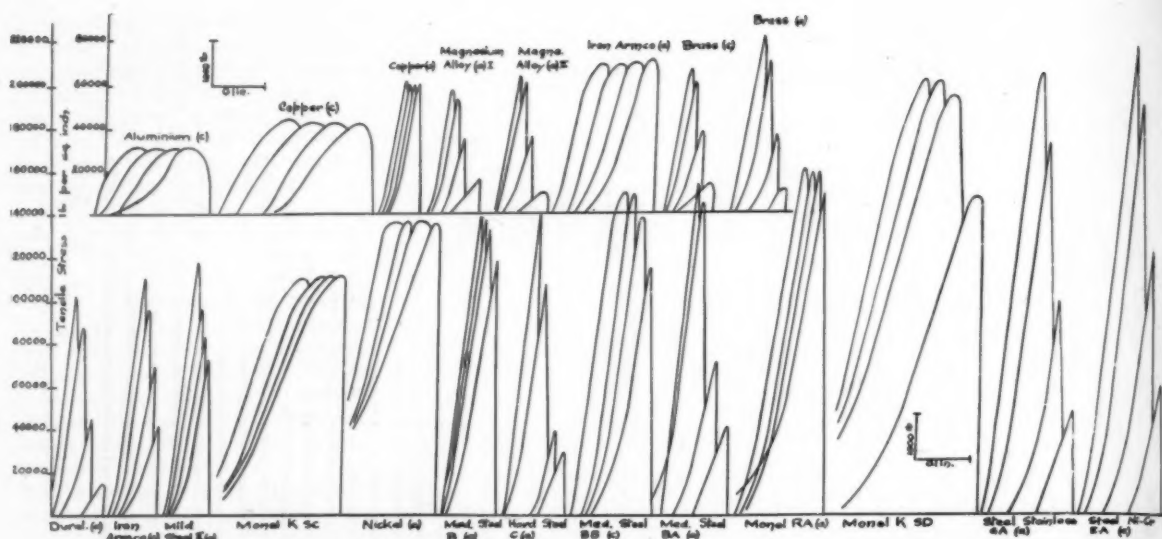
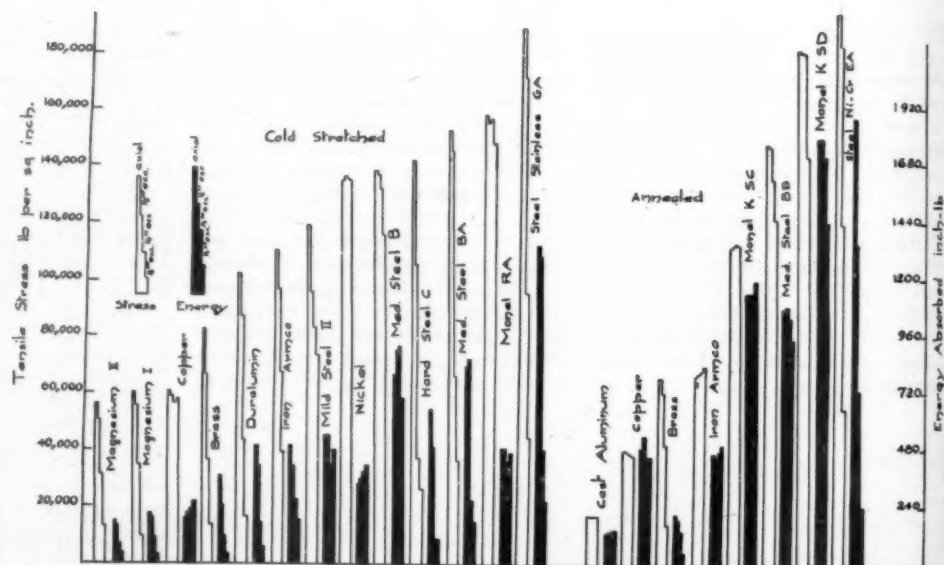


Fig. 20.—Results of stress-strain diagrams of cold-stretched (C) and annealed (A) materials.

On the other hand, despite previous plastic deformation of the material, the decrease in the breaking strength at $\frac{1}{8}$ in. eccentricity is not any greater than in the "as-received" condition. Again with copper, nickel and Monel metal K SC, the breaking strength remains practically unchanged under eccentric loading, while the total energy absorbed is even greater.

The results as illustrated in Fig. 21a would indicate that the pure metals such as cast aluminium, copper and iron have a lower resistance to axial loading in the annealed condition than in the "as-received" condition, while their resistance to eccentric loading is practically the same for the two conditions. On the other hand, it will be noted that the amount of energy required to break the specimens of these materials at $\frac{1}{8}$ in. eccentricity is distinctly higher for the annealed condition (compare Fig. 15, 21 and 21a).



Figs. 21 and 21A.—Classification of cold-stretched and annealed materials in order of increasing stress.

With Monel K SD, the energy is very high at $\frac{1}{8}$ in. eccentricity, and in this respect it is superior to Ni-Cr steel.

To sum up the discussion of results of tests on notched cylindrical specimens loaded under increased eccentricities, it may be said that this testing method affords a measure of the degree of ductility of structural materials. A certain classification of these materials becomes possible, so that the most ductile and resistant, such as Monel metals and special steels, can be

numerically evaluated in comparison with light metals and alloys or other structural materials.

A classification of the various metals and alloys tested with notched specimens axially and eccentrically loaded in tension, according to their ductility and strength properties, will be discussed and presented in tabular form in the concluding part of this report, to be published in the next issue of this journal.

A Post-War View of Alloy Steels in the United States

By Robert S. Archer

Climax Molybdenum Company

Previous work on the standardisation of hardenability testing and on the calculation of hardenability from chemical composition and grain size facilitated the development of NE steels. It is generally found that the best combinations of strength and toughness in steel result from tempering after hardening to a fully martensitic structure. New levels of performance seem attainable as a result of greater knowledge of the conditions necessary for maximum combinations of strength and toughness in steel. Some of the developments during the recent war, discussed by Mr. Archer in a paper before a recent meeting of the American Society of Automotive Engineers, are given in condensed form.

CONSERVATION of alloying elements was the pressing need responsible for an important phase of the wartime work on alloy steels. The first acute shortage to develop was in nickel. This problem was met about May, 1941, by substituting nickel-free SAE steels for the nickel-containing SAE steels. By December of 1941 shortages had developed in chromium and then in molybdenum so that restrictions were placed on the use of these elements as well as nickel. This situation led to the development of the "triple alloy" NE steels.

The guiding principle in the development of these steel compositions was that steels of equivalent hardenability could be used interchangeably. The programme, therefore, involved a great deal of work on hardenability. Fortunately a good start had been made before the war along two important lines: (1) standardisation of hardenability testing, and (2) calculation of hardenability from chemical composition and grain size.

Hardenability

Hardness has been defined broadly as resistance to deformation. In the common Brinell and Rockwell tests the measure of hardness is resistance to permanent deformation by indentation. In ductile steels there is a rather definite relationship between indentation hardness values and tensile strength (tensile strength in pounds per sq. in. equals $500 \times$ Brinell hardness). Indentation hardness tests furnish a similar though less accurate indication of endurance limits as determined in rotating beam tests, since the endurance limit is usually from about 40% to 65% of the tensile strength. Without additional information of some sort, the indentation hardness tests furnish no information regarding ductility or toughness. It is also recognised that these hardness values are not sufficient indications of wear resistance or machinability unless other facts are known. In spite of these shortcomings, hardness tests are frequently the only tests of a metallurgical nature specified for finished parts. Justification for this practice lies, of course, in the fact that additional information is available regarding the composition and heat-treatment of the part. Microstructure furnishes further but still incomplete information regarding such characteristics as toughness and machinability.

The prior development of the Jominy end-quench test¹ proved to be a most important factor in this programme. This test made it possible to obtain quickly and economically hardenability data applicable to a wide range of sizes. The simplicity and utility of the test led to its general adoption in American industry, which had the very important result that hardenability data from many sources became interchangeable. The end-quench test in its usual form is not generally suitable for shallow hardening steels such as plain carbon steels, and is also inadequate for steels to be heat-treated in very heavy sections. The Jominy end-quench test is, however, excellently adapted to the majority of alloy steels used in automotive construction.

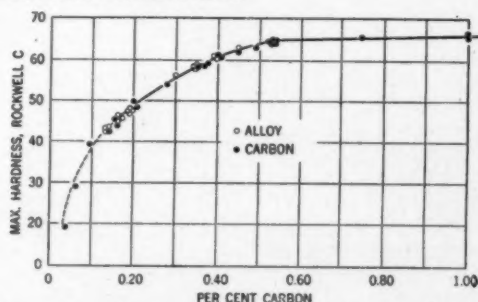


Fig. 1.—Maximum hardness obtainable in plain carbon and low alloy steel.

(J. L. Burns, T. L. Moore and R. S. Archer, "Quantitative Hardenability; Proposed Standard Test," *Transactions of the American Society of Metals*, Vol. 26 (1938).

There are various criteria by which hardenability may be appraised. One method of hardenability testing which has been commonly employed consists of hardening a bar of steel and judging the depth of hardening by fracturing or macro-etching. Grossmann's scheme of determining ideal critical diameters was based on such procedure.² He showed that the transition zone between the hardened exterior and the unhardened interior of a bar, determined in this manner, corresponds to a microstructure consisting of approximately 50% martensite and 50% non-martensitic constituents. In the Jominy test the criterion of hardenability may be the Rockwell

¹ W. E. Jominy and A. L. Boegehold, "A Hardenability Test for Carburizing Steel," *Transactions of the American Society for Metals*, Vol. 26 (1938).

² M. A. Grossmann, M. Asinow and S. F. Urban, "Hardenability, Its Relation to Quenching and Some Quantitative Data," "Hardenability of Alloy Steels" (published by the American Society for Metals, 1939).

C hardness at a given distance from the water-cooled end of the specimen, or the distance at which a given hardness value is found. Hardness values depend both on the intensity of hardening obtainable as determined by carbon content (see Fig. 1) and on the depth hardening characteristics of the steel as determined by its critical cooling rate. Many investigators seek to determine the microstructure at various distances from the water-cooled end of the Jominy bar, in addition to the Rockwell C hardness. The correlation between microstructure and hardness has been found to vary somewhat from one type of steel to another, whenever non-martensitic structures are present.³ If a group of steels of different types but of the same carbon content is arranged in order of increasing hardenability as measured by the distance at which a certain hardness value is found, the order is not necessarily the same as when hardenability is appraised by the depth of martensitic hardening determined by microscopic examination.

Attempts to estimate the hardenability of steel from chemical composition and grain size have been made for some time. Several schemes for doing this were proposed and used. They were generally based on the addition of various factors or indices and were restricted with respect to range of chemical composition. In 1942 Grossman presented his method of calculating hardenability, which involved the novel concept of multiplying certain indices rather than adding them.⁴ He also determined by experiment suitable indices or factors to be used for the various significant elements in steel. The multiplying factors were determined for the percentages of each element ordinarily used in automotive and similar steels, so that the scheme as a whole has a wide range of application with respect to chemical composition.

In developing the NE steels, the Grossman method was widely used in predicting the hardenability of new compositions and the Jominy test made it possible for many co-operating investigators to accumulate actual hardenability data rapidly. The original Grossman factors were admittedly subject to revision as more data were accumulated, and some have questioned whether the principle is valid for all the composition ranges to which it has been applied.^{5, 6, 7} Experience demonstrated that the results obtained by the calculations were sufficiently accurate to be very useful. It is too much to expect that any method which is so simple can evaluate accurately and completely the effects of all of the variables involved in the hardening of steel.

Brittle Failures

It has long been recognised that stress concentrations due to notches, tool marks, oil holes and the like, may lead to brittle failures in steels which otherwise appear to be ductile. The extensive application of magnetic particle inspection methods for the detection of cracks, seams and large non-metallic inclusions in finished parts subject to high stresses is based on the recognition that these defects also are "stress raisers." Certain items of

war material required in very large volume differ from most peacetime products in that unusually high rates of load application are involved, which lead to brittle failures. It is also well known that low temperatures are apt to lead to brittle failures.

The problem of determining the effects of non-uniform stress distribution on deformation and failure is one of great complexity, and does not appear as yet to have been satisfactorily solved even for such an apparently simple case as a notched tensile test specimen.⁸ Stress distributions existing during the substantially elastic stage of deformation are greatly altered when even a small amount of plastic deformation takes place. Stress conditions which are conducive to brittle failure have been described in various terms such as—stress concentration, transverse stress, biaxial stresses and triaxial stresses. For convenience we will refer to any stress condition which promotes brittle failures as "stress concentration." It appears at present to be impossible to predict in a quantitative manner the effect of stress concentration in an engineering part or structure of complex shape. It is, nevertheless, valuable to recognise qualitatively the effect of stress concentration on deformation and rupture.

The fact that Charpy and Izod tests are called "impact tests" indicates that they were intended to measure the toughness of material under conditions of impact or high velocity loading. Actually, the striking velocity in these tests is quite low (on the order of 15 ft. per sec.) as compared with velocities frequently encountered in peacetime service, to say nothing of ballistic velocities. Experiments have shown that for many engineering steels the energy required to break the notched impact specimen may be almost the same whether the specimen is broken by slow bending or in the impact machine.^{9, 10} It is accordingly recognised that the Charpy and Izod tests measure notch sensitivity rather than the effect of high rate of load application, and they are now frequently referred to as "notched-bar tests" or "notched-bar impact tests." Attempts to measure energy of rupture at striking velocities approaching ballistic velocities seem to involve some serious experimental difficulties, one of which is that the kinetic energy imparted to the fragments of the specimen constitutes a substantial part of the total energy absorbed.

Work done at Watertown Arsenal has led to the conclusion that the effect of increased striking velocity is equivalent to the effect of decreased temperature of test. The following equation relating these factors has been proposed.¹¹ Under isothermal conditions, material will behave at a temperature, T and a strain rate $\dot{\epsilon}$ as at room temperature, T_r and an equivalent strain rate = $\dot{\epsilon}_e Q/RT / \dot{\epsilon}_e Q/R T_r$

where $\dot{\epsilon}$ = strain rate
 T = temperature
 Q = heat of activation
 R = gas constant (2 cal./gm. mol/°C)

As an illustration of the magnitude of the effect, Hollomon¹² pointed out that a lowering of temperature

³ W. Crafts and J. L. Lamont, "Effect of Some Elements on Hardenability," *Transactions, American Institute of Mining and Metallurgical Engineers*, Vol. 158 (1944).

⁴ M. A. Grossman, "Hardenability Calculated from Chemical Composition," *Transactions, American Institute of Mining and Metallurgical Engineers*, Vol. 159 (1942).

⁵ W. Crafts and J. L. Lamont, "Addition Method for Calculating Rockwell C Hardness of the Jominy Hardenability Test," T.P., 1928, *Metals Technology*, October, 1945.

⁶ G. B. Brophy and A. J. Miller, "An Appraisal of the Factor Method for Calculating the Hardenability of Steel from Composition," T.P., 1933, *Metals Technology*, Oct., 1945.

⁷ J. H. Hollomon and L. D. Jaffe, "The Hardenability Concept," T.P., 1926, *Metals Technology*, Jan., 1946.

⁸ A.I.M.E. Symposium on Cohesive Strength. *Trans. A.I.M.E.*, Vol. 141 (1945).

⁹ E. Maurer and R. Mailander, "On the Question of Blue Brittleness," *Stahl und Eisen*, Vol. 45 (1925).

¹⁰ H. F. Moore, H. B. Wishart and S. W. Lyon, "Slow Bend and Impact Tests of Notched Bars at Low Temperatures," *Proceedings, American Society for Testing Materials*, Vol. 36 (II) (1936).

¹¹ C. Zener and J. H. Hollomon, "Effect of Strain Rate on Plastic Flow of Steel," *Journal of Applied Physics*, Vol. 15 (1944).

¹² J. H. Hollomon and C. Zener, "Conditions of Fracture of Steel," *Transactions, American Institute of Mining and Metallurgical Engineers*, Vol. 158 (1944).

by 90° F. is equivalent to an increase in strain rate of at least 1,000 fold. It is comparatively easy to make notched-bar impact tests at low temperatures.

It is thus seen that there are three important factors which contribute to brittle failures in steel:—

- (1) Stress concentration
- (2) Low temperature, and
- (3) High rate of loading.

Whether or not these three factors are related to each other in an exact manner under all conditions, it is clear that their effects are qualitatively similar. In order to appraise the tendency of steel to fail in a brittle manner it is now considered necessary to evaluate in some way the effects of all of the three factors mentioned. A practical method of doing this is to make notched-bar impact tests at as many different temperatures as is necessary to establish a complete impact vs. temperature curve as illustrated by the schematic diagram in Fig. 2.

By a complete curve is meant one which shows the transition from tough to brittle fractures which commonly occurs in ferritic steels. At the higher temperatures failure is accompanied by plastic deformation, high energy absorption and fractures which appear fine, silky or fibrous because of the plastic deformation itself. At the lowest temperatures failure takes place with very little plastic deformation, with low energy absorption and with fractures which appear brittle and sometimes coarse because of the absence of plastic deformation. In the intermediate or transition range, fractures may exhibit mixed characteristics, and the energy values are apt to vary considerably between duplicate tests.

A high transition temperature range in the impact-temperature curve is conducive to brittle fractures. It indicates that an accentuation of any of the three unfavourable factors—stress concentration, low temperature or high rate of loading—is apt to cause failure in a brittle manner. Conversely, a lower transition temperature indicates that the steel is more capable of withstanding any one or any combination of the unfavourable factors. Thus notched-bar impact tests at low temperatures not only indicate the suitability of the steel for service at low temperatures, but also indicate the suitability of the steel under conditions involving high stress concentrations or high rates of loading.

In determining the impact-temperature curve the three variables are under rather good control. The stress concentration factor is kept constant by using test specimens of the same design, with special reference to the accuracy of the form and finish of the notch. Temperature is more easily controlled in the Charpy than in the Izod test because the Charpy specimen is not held tightly in a grip as is the Izod specimen. Experi-

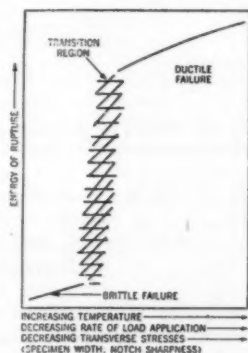


Fig. 2.—Schematic diagram showing the effect of temperature of test on the notched-bar impact values of a non-austenitic steel.

(C. Zener and J. H. Hollomon, "Plastic Flow and Rupture of Metals," *Transactions, American Society for Metals*, Vol. 33, 1944).

ments have shown that only a negligible change in temperature need occur during the time between the removal of the specimen from its cold environment and its actual breaking in the testing machine. The velocity of striking is, of course, determined by the characteristics of the testing machine, and in a given type of machine does not vary enough to affect the results appreciably.

One of the potential causes of brittle failure is the phenomenon known as "temper brittleness." Researches carried out largely in connection with military requirements have led to a new conception of this subject. A common manifestation of temper brittleness is that specimens of hardened steel which have been cooled slowly after tempering at about 1,200° F. exhibit substantially lower notched-bar impact values than corresponding specimens which have been quenched after tempering at the same temperature. The tensile properties are apt to be practically the same in both cases, indicating that the greater sensitivity of the notched-bar test is required to detect this type of embrittlement. Formerly, impact tests to detect temper brittleness were made at room temperature. The ratio of the impact value, after quenching from the tempering temperature, to the impact value after furnace cooling from the tempering temperature, was regarded as a measure of the susceptibility of the steel to temper brittleness. If this ratio

$$\frac{\text{impact as-quenched}}{\text{impact as-furnace-cooled}}$$

was approximately 1, it was considered that the steel was not susceptible to temper brittleness. Ratios as high as 25 have been observed. For example, a certain heat of nickel-chromium steel made during the first world war for aircraft engine crankshafts had Izod impact values around 50 ft. lb. when quenched after tempering, and Izod values of only 2 ft. lb. when furnace-cooled after tempering.

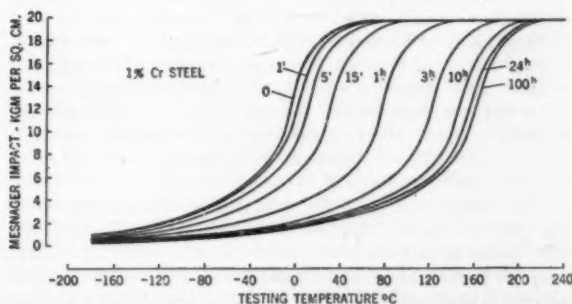


Fig. 3.—Effect of tempering time at 975° F. on the temperature impact curves of steel containing 0.25% C, 0.30% Mn, 0.32% Si and 1.38% Cr, Steel oil-quenched from 1605° F. Brinell hardness 241 after all tempering treatments.

(G. Vidal, "Revue de Metallurgie," Vol. 42, 1945).

It was early recognised that the degree of susceptibility to temper brittleness indicated by the ratio of room temperature impact values may vary considerably among different heats of the same grade of steel. One belief which gained wide acceptance was that acid steels are more susceptible to temper brittleness than basic steels. It is now considered more probable that certain variations resulting from steel-making practices, such as the phosphorus content and the amount of aluminium

addition, have the effect of shifting the entire impact vs. temperature curve to higher or lower temperatures without necessarily affecting the susceptibility to temper brittleness. A shift in the temperature of the transition from high to low impact values could have the effect of greatly changing the temper brittleness susceptibility ratio determined by impact tests made at only one temperature such as room temperature. (Fig. 3). A more complete picture of the phenomenon is obtained by making sufficient tests at various temperatures to determine the impact vs. temperature curve.

For some of the common types of alloy machinery steels the evidence indicates that temper brittleness is developed in a range below about 1,100° F., either as a result of cooling slowly from a higher temperature or as a result of reheating to some lower temperature such as 975° F. The time required to develop the brittleness seems to be longer the lower the temperature in the range below approximately 1,100° F. Obviously, if the required hardness of the steel after tempering is such that the tempering temperature itself must be in the range which produces embrittlement, then embrittlement will occur regardless of whether the steel is cooled slowly or rapidly after the tempering operation.

Recent researches indicate that susceptibility to temper brittleness increases with the total hardenability of the steel. It has been found by various investigators^{13, 14, 15, 16} that, in steels of moderate hardenability, molybdenum partially or entirely prevents the development of temper brittleness in normal heat-treating operations. The indications are that the amount of molybdenum required for this purpose increases with the hardenability of the steel, and that additions up to about 0.5% are effective for this purpose. It has been suggested¹⁶ that columbium and tungsten may also be effective.

Martensitic Structure

The best combinations of strength and toughness are generally found in steel which has been tempered after having been hardened to a fully martensitic structure. When fully martensitic hardening is not obtained, the nature and distribution of the non-martensitic constituents are important. In steels of low and medium carbon content these constituents are ferrite, pearlite and bainite. Two types of bainite may be distinguished—upper bainite, formed at temperature just below the lowest temperatures at which lamellar pearlite can form, and lower bainite, formed at temperatures just above the point at which martensite begins to form. With respect to toughness after tempering, ferrite and pearlite are most detrimental. Free ferrite at grain boundaries is particularly detrimental at high hardness levels of the steel as a whole, on account of the marked contrast in strength between the ferrite and the interior portions of the grains. The ferrite will not withstand sufficient stress to plastically deform the harder constituents. Upper bainite is in general less detrimental than ferrite or pearlite, and lower bainite may after tempering be very nearly as tough as tempered martensite. The effects of free ferrite and pearlite are usually brought

out by notched-bar impact tests made at room temperature, while the effects of bainite on toughness may be revealed only when the severity of the test is increased, as by lowering the temperature of testing. (Fig. 4).

Certain problems are in the way of obtaining fully martensitic hardening in practice. One is based on the belief that martensitic hardening is apt to cause more distortion or quench-cracking than partially martensitic

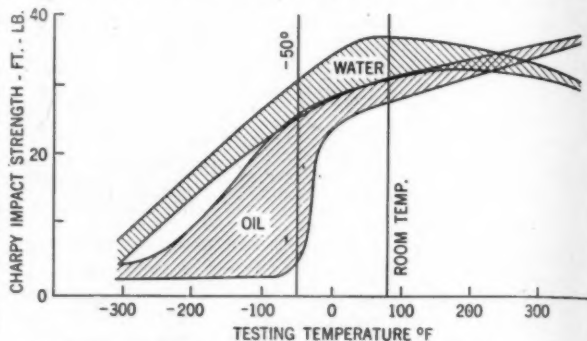


Fig. 4.—Effect of quenching rate and hence of as-quenched structure on the notched-bar impact properties of S.A.E. 1045.

(H. W. Gillett and Francis T. McGuire, "Report on Behaviour of Ferritic Steels at Low Temperatures," Part II. Published by the American Society for Testing Materials, Dec., 1945).

hardening. This may be true in certain cases, but such difficulty might be avoided by selecting a steel of lower carbon content or by the use of special quenching methods. Another consideration is the fact that steels of higher hardenability often involve higher initial cost. The problem is one which requires careful consideration of various factors involved in manufacturing operations and in service. Boegehold has published a curve¹⁷ which suggests that for best properties after tempering the hardness as quenched should be not more than about ten points Rockwell C below the maximum hardness obtainable for the carbon content of the steel under consideration. This would correspond for most grades to structures containing minimum amounts of martensite from about 85% to 95%. The type of structure decided upon for the finished part determines the degree of hardenability required and thus affects the selection of a suitable steel. The significance of this is emphasised by Hodge and Orehsoski.¹⁸

Triple Alloy Steels

The development of the H steels recognises current opinion that the first consideration in the selection of an alloy steel is that it must have a degree of hardenability suitable for the intended application. The H steels guarantee a definite "band" of hardenability for each grade. The type of steel is specified as formerly by chemical analysis, but slightly wider ranges are permitted in view of the recognition that small variations in composition are not important providing hardenability is maintained within the desired band. The development

13 R. H. Greaves and J. A. Jones, "Temper Brittleness of Steel," *Journal of the Iron and Steel Institute*, Vol. III (1925).

14 W. E. Goodrich, "The Embrittlement of High-Tensile Alloy Steels at Elevated Temperatures," *Journal of the Iron and Steel Institute*, Vol. 133, No. 1 (1936).

15 E. Maurer, O. H. Wilms and H. Klesner, "Brittleness in Alloy Steels," *Stahl und Eisen*, Vol. 62 (1942).

16 J. H. Hollomon, "Temper Brittleness," *American Society for Metals*, Preprints No. 11 (1945).

17 A. L. Boegehold, "Selection of Automotive Steels on the Basis of Hardenability," (*Transactions*) *Journal, Society of Automotive Engineers*, Vol. 52 (1944).

18 J. M. Hodge and M. A. Orehsoski, "Relationship Between Hardenability and Percentage of Martensite in Some Low Alloy Steels," *Metals Technology*, Sep., 1945 (American Institute of Mining and Metallurgical Engineers, Technical Publication 1800).

of these steels offers the advantages that some of the heats which would otherwise require special consideration can be handled in a routine manner, and that such heats comply with the original specifications.

Just how closely hardenability needs to be controlled depends on the intended use of the steel. In general, however, the consumer desires that the hardenability bands be as narrow as it is practicable for the steel producer to make them. By using the information now available regarding the quantitative effects of the various elements on hardenability, it is possible to calculate hardenability bands corresponding to the extreme variations in chemical analysis permissible for a given grade of steel under standard specifications. It is recognised that theoretical bands calculated in this manner are too wide for a great many applications. It is also recognised that it is not likely that many heats of a given grade will have all of the hardening elements on either the high side or the low side at the same time. To determine how narrow the hardenability band may be made without encountering an undue percentage of heats which are outside the band will require extensive experience in the production of the H steels so that adequate statistics can be accumulated. There are so many factors which affect the control of chemical composition and hardenability in steel-making that it appears impossible to calculate the narrowest practicable bands by probability methods.

A question which has often been discussed since the end of the war concerns the merits of the "triple alloy" steels in comparison with the old grades. The three alloying elements indicated by the term "triple alloy" are chromium, molybdenum and nickel. Substantially all of the molybdenum and nickel contained in scrap is recovered on re-melting by any process, and some of the chromium is recovered on re-melting, especially in the electric furnace process. Presumably, vanadium was not included in these steels because it was scarce and because of the fact that it is not recovered in tonnage melting processes. Chromium-molybdenum-nickel steels are not new, since these elements were used in combination with each other for many years before the war. Formerly, however, these three alloying elements were generally used together only when fairly high hardenability was required. The novelty about the NE triple alloy steels is that chromium, molybdenum and nickel are used in steels of moderate hardenability. The question is whether this practice is advantageous or otherwise in comparison with the use of a smaller number of alloy elements.

The advantage of the triple alloy steels was obvious when alloy conservation was a war necessity, in view of the impracticability of adequate scrap segregation. Conservation remains important in peacetime because of both the cost of alloy additions and the fact that supplies of alloying elements are not inexhaustible. The triple alloy steels are probably of more immediate interest to the consumer because of the fact that all the alloying elements are under positive control, which should be conducive to greater uniformity of behaviour.

The importance of hardenability in the selection of steel is unquestioned, but it should not be assumed that hardenability is the only consideration of importance. The suggestion has even been made, perhaps not seriously, that steel may be specified in terms of hardenability alone without any regard to chemical composition. It seems evident that carbon content and the general

composition of the steel with respect to alloying elements also need to be specified, if for no other reason than to permit the maintenance of fixed fabricating and heat-treating operations. Furthermore, steels having almost identical Jominy curves in the hardened condition do not necessarily have the same mechanical properties when tempered to a given hardness.

The general formula for the selection of materials remains the same: the proper material is the one which gives satisfactory performance at the lowest ultimate cost. However, each of the factors in this formula is complex and requires re-evaluation in the light of new technical information and economic changes. Ultimate cost refers to the cost of finished parts rather than to that of raw materials. Steels of equivalent hardenability may vary considerably with respect to fabricating costs, including such items as forging, cleaning, annealing, machining, heat-treating, straightening and inspection.

The uniformity with which a material responds to processing is obviously important because of the increasing importance of the labour factor. A simple illustration of the bearing of this factor on the selection of material may be found in certain parts which may be made of either a water-hardening or an oil-hardening steel. In some cases such parts have been hardened in water with some distortion and risk of quench-cracking in order to effect savings in the cost of raw material. Oil-hardening may result in the saving of work which would otherwise be expended in inspection, salvaging and rejections to an extent which will more than compensate for the initially higher cost of the oil-hardening steel.

Satisfactory performance is a relative term. Machines could be built which would operate with a reasonable degree of satisfaction if made of materials substantially inferior to those available during the past twenty years. In general, however, we would not be fully satisfied with such machines, and likewise we will not be satisfied with present machines if still more satisfactory performance can be achieved. Except when rigidity is the primary requirement, it is usually desirable to be able to operate at higher stresses, which means higher hardness and strength. Two factors which have limited the strength at which steel is used are the difficulty of machining at high hardness and the lack of toughness. Improvements in machine tools and cutting materials promise in some cases to raise the hardness at which machining is commercially practicable. The information gained during the past few years regarding the conditions necessary to insure maximum toughness in steel at a given hardness level suggests the possibility of improvements in design and performance based on consistently superior combinations of strength and toughness.

MR. C. W. KAYSER, J.P., who has been Chairman and Managing Director of Kayser Ellison and Co., Ltd. since 1906, has resigned, but will continue to serve as a Director. As a result the following changes in the Board of this company are announced: Mr. L. A. K. Halcumb, who became a Director in 1919, Joint Managing Director and Deputy Chairman in 1941, is now Chairman and Joint Managing Director. Mr. P. B. Henshaw, who became a Director in 1915 and Joint Managing Director in 1941, is now Deputy Chairman and Joint Managing Director. Mr. H. Francis, M.B.E., retires from the Board, and Mr. E. Ransom Harrison, Chairman of the Rover Co., Ltd., has joined the Board.

Recent Developments in Materials for Gas Turbines

A recent issue of the Proceedings of the Institution of Mechanical Engineers contains a series of ten lectures delivered at the March, 1946, symposium on the development of the internal combustion turbine. The lecturers present the most comprehensive survey yet published of the work done in this field in Great Britain. One of the lectures—by Dr. T. A. Taylor, of Power Jets (Research and Development), Ltd.—deals with the question of materials and the present summary is confined to the development of the materials discussed.*

EVERY aspect of development, design and performance of the internal combustion turbine is described in a recent series of lectures, all of which are profusely illustrated. In an introductory address to the lectures Mr. Hayne Constant points out that the output possible from a gas turbine depends more on the maximum gas temperature that can be used than on anything else, and this involves the field of high-temperature materials for which there is an insistent demand. He paid tribute to the work of the Mond Nickel Company in giving to this country the best high-temperature materials in the world. This question of materials, which is rightly regarded as one of the most fundamental in the development of gas turbines, is discussed by Dr. T. A. Taylor under the heads of components for which the provision of materials gave the greatest difficulty and the following summary presents some of the main features of his lecture.

Turbine Blades

Turbine blades were one of the most critical components and at the outset the requirements of the blade designer were more difficult to meet than those of any other component. Prior to 1939, the best materials available were only able to withstand the stresses needed for the Whittle engine up to 550° C. without excessive creep. "Stayblade" one of the best of these alloys, and produced from the Brown-Firth Research Laboratories, was used in Whittle's initial experimental work, but was not expected to withstand full-load conditions. In 1939, however, an austenitic nickel-chromium steel with considerably improved properties was made available by these latter Laboratories, under the name of Rex 78. Development at this stage required a material which would have a life of 1,000 hours without fracture under a load of 13-15 tons/sq. in. at 650° C. While Rex 78, in its original form, would not fully meet these requirements, it represented a great advance on materials then available and permitted great strides in engine development. The stress-temperature curves for Rex 78 and "Stayblade," reproduced in Fig. 1, show the improvement of the former alloy.

Rex 78 has a nominal† percentage composition of: carbon, 0.08; nickel, 18.0; chromium, 14.0; molybdenum, 4.0; copper, 4.0; titanium, 0.6; iron, remainder. Its creep properties were subsequently improved by heat-treatment, consisting of air cooling from 1,050° C., followed by successive reheatings at 800° C. and 600° C., respectively.

* *Proc. Inst. Mech. Eng.*, 1945, **153**, pp. 409-512. (War Emergency issue No. 12).

† The chemical compositions given in this lecture are nominal and only elements of major importance are listed.

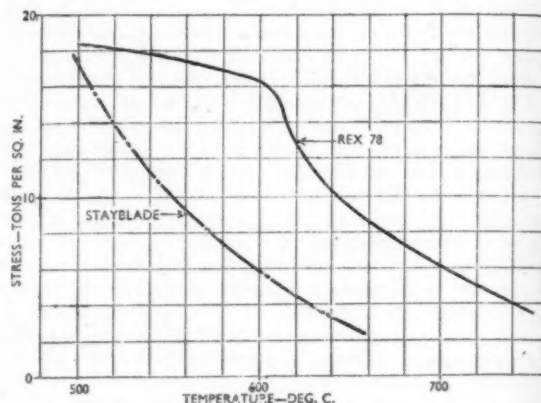


Fig. 1.—Stress-temperature curves for Stayblade and Rex 78.

Plotted stress is the Hatfield "time-yield" value, i.e., the stress producing a rate of creep not exceeding 10^{-6} in. per in. per hr. between the 24th and 72nd hours.

Following the adoption of Rex 78, two other alloys were considered for use as blading materials. The first of these was not a steel but a nickel-base alloy known as "Nimonic 75," the second alloy was a complex nickel-base alloy known as "K42 B" produced by the Westinghouse Company, U.S.A. A series of creep tests were carried out which showed that K42 B had very similar creep properties to Rex 78, though its hardness and mechanical properties in the cold and at elevated

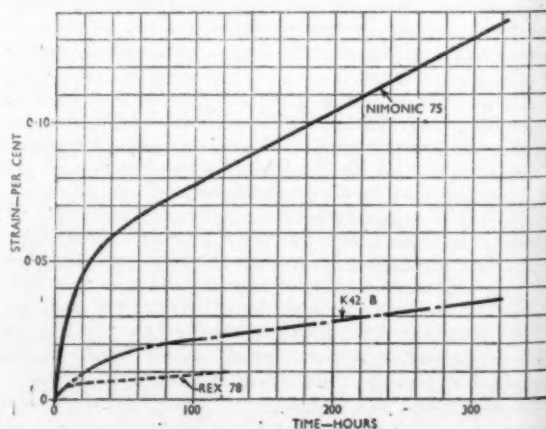


Fig. 2.—Strain-time curves for Rex 78, K42 B, and Nimonic 75 under the same stress at 650° C.

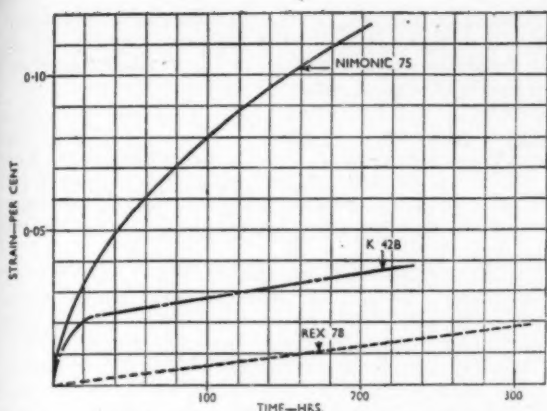


Fig. 3.—Strain-time curves for Rex 78, K42 B, and Nimonic 75 under equivalent stress at 700° C.

temperatures were very much superior. Some properties of these two alloys are summarised in Table I. Comparative creep curves for the three alloys under the same stress at 650° C. are reproduced in Fig. 2 and a similar set of curves under equivalent stress at 700° C. is shown in Fig. 3.

TABLE I.—COMPARISON OF MECHANICAL AND CREEP PROPERTIES OF REX 78 AND K42 B.

	20° C.		600° C.	
	Rex 78	K42 B	Rex 78	K42 B
0.2% proof stress, tons/sq. in. . .	23.9	46.5	13.5	38.5
Ultimate tensile stress, tons/sq. in.	48.5	73.0	33.1	56.5
Elongation, %	41.0	29.0	39.5	21.5
<hr/>				
Creep rate (at 100 hours) :— 7 tons/sq. in. at 650° C.	Rex 78		K42 B	
	5 × 10 ⁻⁷ in. per in. per hr.		7.5 × 10 ⁻⁷ in. per in. per hr.	

With the steady improvement in engine performance the service conditions which the turbine blades were called upon to withstand became increasingly severe, and failures of the Rex 78 material became more frequent. About this time, however, the position was improved and development speeded up by a new alloy developed by The Mond Nickel Company Ltd. and manufactured by Henry Wiggin & Co. Ltd. This alloy, known as "Nimonic 80," had creep properties vastly superior to those of the alloys previously mentioned, and, despite the great number of alloys that have been made and tested since its introduction, it has maintained its supremacy as the best alloy for turbine blading.

Nimonic 80 is similar in type to Nimonic 75, but is of slightly modified composition and is subjected to special heat-treatment. Its creep properties in comparison with those of Nimonic 75 are shown in Fig. 3. Since the introduction of this alloy, modifications in design have developed with improvement in materials of construction, with the result that full advantage could be taken of the new alloy, and in present-day engines it is not uncommon to encounter centrifugal stresses of 12 tons/sq. in. with blade temperatures of 700° C. Design development continues to demand still better materials, and it is confidently believed that new alloys being developed will improve the reliability of

present engines and give new opportunities to the designers of increasing the severity of the conditions.

Brief notes are given on American and German developments. In both countries considerable attention has been given to the development of high-temperature materials. In the United States many alloys have been tested, but the most widely used has been Hastelloy B, well known before 1939 for its corrosion resisting qualities. Despite the handicap of shortage of materials, a number of alloys have been developed in Germany for jet propulsion. The most prominent of these was Tinidur, a nickel-chromium-titanium alloy having the nominal percentage composition of: carbon, 0.1; nickel, 30.0; chromium, 15.0; titanium, 1.8. The serious shortage of raw materials for creep-resisting alloys had caused the Germans to develop ceramic materials, such as fused silica, silicon carbide and sintered alumina, for blades, and a considerable degree of progress had been made. The ceramic materials were found to be rather sensitive to thermal shock and so experiments were being made with sintered mixtures of iron powder and refractory oxides in an attempt to improve the thermal conductivity and resistance to temperature gradients; the composition of the material could thus be varied along the length of the blade if desired.

Method of Manufacture.—Blades for all the early experimental engines were made from forged rectangular bar by milling on standard machine tools. The rate of production was slow and a special cam-operated turning and grinding machine was subsequently designed by Mr. A. J. Kestell, which permitted the generation of a wider range of blade contours. In 1941, drop forgings in Rex 78 were produced by Firth-Derihon Stampings, Ltd., as a means of conserving material. Early in 1942 a great drive was made in the United States to produce precision drop forgings in "Hastelloy B," which were claimed to require no machining. A similar development took place in Britain and "close" forgings in Rex 78

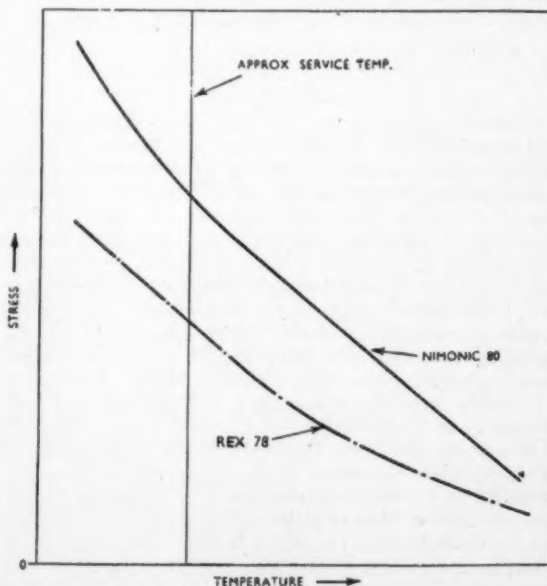


Fig. 4.—Stress-temperature curves for Rex 78 and Nimonic 80, based on 0.1% creep in 300 hours.

and Nimonic 80 were produced, but subsequent experience showed that it was better to leave a small machining allowance. The Mond Nickel Co. introduced the technique of electro-machining—i.e., the anodic dissolution of metal from the surface, as a means of removing excess material. While this latter process has not found general application as a method of finishing blading, it has been retained in the process of manufacture of Nimonic 80 blades, since it constitutes a valuable method of detecting surface defects during the forging operations.

Desirable Characteristics.—In addition to the possession of adequate strength, there are a good many other qualities which go to the making of the ideal turbine blade material. These are listed as adequate endurance, erosion-resistance, stability, uniformity in mechanical and physical properties, oxidation resistance, forgeability, castability, weldability, and machinability.

Future Requirements.—It is widely realised that increase in gas temperature in a gas turbine results in greater efficiency. The design engineer has constantly in mind, therefore, the highest gas temperature which the available materials will allow. During the period under review, turbine blade temperatures have steadily risen from 600°–700° C., and it seems reasonable to expect that normal development will enable this temperature to be raised to 800° C. in the near future. The rise in temperature service will tend to narrow down the range in which hot forging is possible, since the minimum temperature at which plastic deformation by hot working can be carried out will be correspondingly increased. For this reason, turbine blades made by precision casting may find a wider application. Eventually, as the melting points of the elements normally used in making high-temperature materials are more closely approached, it will be increasingly difficult to provide adequate creep properties. At this stage, new types of alloys, employing the more refractory metals will perhaps be explored, and the field of powder metallurgy may be invaded. Alternatively, we may have to attach increasing importance to the development of ceramic materials, to which the recent German work has lent an added interest.

Turbine Discs

Generally speaking, material for turbine discs has not been so difficult a problem as that for turbine blades, although failures have occurred. In one experimental engine the temperature at the rim of the disc under full-speed conditions was estimated to be 500°–550° C. Stayblade was the alloy chosen on account of its higher creep strength. The nominal percentage composition of Stayblade is: Carbon, 0.2; nickel, 8.0; chromium, 20.0; titanium, 1.2; iron, remainder. This alloy continued in use for practically all the development work up to the latter part of 1943, when a series of failures were encountered due to an excessive temperature being attained at the rim of the disc, which resulted in the tearing away of the blades and part of the root fixing.

It was decided that Stayblade did not allow for a sufficient margin of safety against temperature rise, and materials of higher creep strength were introduced. The most popular of these has been G18 B made by Messrs. W. Jessop and Sons, Ltd., which is the standard material used on "Derwent" and on W2/700 engines. Its nominal percentage composition is: carbon, 0.40; nickel, 13.5; chromium, 13.5; tungsten, 2.5; molyb-

denum, 2.0; cobalt, 10.0; niobium and tantalum, 2.8. One disadvantage found with this material when first tested was the excessive growth which occurred in the first few hours of running. It was found that heat-treatment at 800° C. reduced this initial extension, and brought it within acceptable limits. An appreciable improvement in proof stress at room temperature, and in the creep strength at high temperatures, has been obtained by plastic deformation below the normal range of temperature used for forging, designated "warm working."

Rex 78 has also been used successfully to some extent and it will thus be realised that the austenitic steels have been chiefly used for discs in British gas turbine development. In some cases it has been found possible to use ferritic steels of the silicon-chromium, chromium-molybdenum, and molybdenum-vanadium types, but the sharp fall in creep strength above 500° C. of many of these alloys places limitations on their use.

Methods of Construction.—Up to the present all discs have been made as forgings. Most of these have included a stubshaft forged integrally with the disc, and it is pointed out that much credit is due to manufacturers for mastering the technique of making forgings of this size, with widely differing diameters, in creep-resisting austenitic material. A new method was introduced into the manufacture of G18 B discs, in which the shaft was flash-welded to a very short extension on the disc. The shaft was made from a much simpler austenitic steel, since good creep properties are not of importance, owing to the lower service temperature at this point.† Some engine builders have used discs with a bolted-on shaft. This simplifies the forging problem greatly but complicates the disc design by increasing the stress.

American Developments.—Several different disc materials have been tested, and many more proposed as suitable. The most widely used has probably been Timken alloy, whose nominal percentage composition is: carbon, 0.1; chromium, 16.0; nickel, 25.0; molybdenum, 6.0; iron, remainder. This alloy had previously been used extensively for turbo-supercharger rotors, and valuable experience concerning its manufacture and properties were therefore available.

German Developments.—An austenitic steel was used for the initial development of one of the German jet engines, but shortage of alloying elements resulted in a complete changeover to ferritic steels, which were intensively developed. One of the most prominent of these was a chromium-molybdenum-vanadium alloy having the approximate percentage composition of: carbon, 0.2; chromium, 2.8; molybdenum, 0.4; vanadium, 0.8; iron, remainder. Unusually high creep strength was obtained in the temperature range 500°–600° C. from this type of material by means of heat-treatment which involved an interrupted quench and subsequent tempering at 600°–700° C. In connection with German practice it should also be remembered that great attention was paid to the air cooling of blades and discs, and disc temperatures were claimed not to exceed 350° C.

Future Requirements.—The trend to higher gas temperatures almost inevitably means a rise in the temperature at the rim of the disc. Materials with

† Described by D. A. Oliver and G. T. Harris in a paper entitled, "Gas Turbines: Work on Flash-Butt-Welded Discs and Shafts." *Iron and Steel*, 1946, 19, 379–381, and *Welding*, 1946, 14, 231–235.

adequate creep strength at these higher temperatures will be wanted, and this will accentuate the importance of forgeability. It will also open up the possibility of using cast rotors. The third alternative, the development of ceramic rotors as foreshadowed by German experiments, seems at the present time to be a rather remote possibility which will take a long time to develop to the stage of practical utility.

Turbine Nozzle Assembly

A variety of materials has been tested in this connection, most of these having also seen service in the form of rotor blading. All the alloys tried have certain disadvantages, and a really suitable material for the purpose has not yet been found. In the Whittle experimental and W1 type engines, which had a gas-temperature of about 800° C., the nozzle guide vanes were made of Stayblade. These proved reasonably satisfactory for the short periods of testing then used, but more prolonged running led to distortion and Rex 78 was substituted, in the hope that its higher creep-strength would reduce distortion. With longer periods of engine-testing, however, other limitations of the alloys became apparent. The amount of scaling and pitting occurring on Stayblade and Rex 78 blades was considered excessive, and materials with greater resistance to oxidation, such as Nimonic 75 and 80, were tried. Distinct improvement in resistance to surface-deterioration was thus obtained, but distortion was not entirely eliminated and the problem has not yet been completely overcome. Precision-cast Vitallium nozzle guide vanes have been used on Derwent engines, but these also are prone to distortion. The characteristics desirable in a material for turbine nozzle assemblies are considered to be complete resistance to progressive oxidation, resistance to distortion, creep-resistance and adequate resistance to erosion.

Reference is made to the development, in Germany, of an austenitic steel containing 18% of manganese and 12% of chromium. The steel was produced in the form of sheet, from which hollow guide vanes were made by folding into an aerofoil shape and spot-welding along the trailing edge. Dr. Taylor pointed out that it is likely that, unless air-cooled, this steel would have insufficient resistance to oxidation and that it is therefore improbable that it could be successfully used for solid blades.

Combustion Chambers

For flame tubes, Immaculate 5 (a 25-20% chromium-nickel steel) was initially used, but this material proved to be susceptible to buckling. Nimonic 75, in sheet form, was then tried, as a means of obtaining the higher strength at elevated temperature and the lower coefficient of expansion which would give greater resistance to distortion. Attempts to roll Nimonic 75 into thin sheet were successful (although freedom from surface defects was somewhat difficult to obtain), welding qualities were satisfactory, and, when the sheet was made up into flame tubes, the anticipated improvement in performance was obtained. Inconel (carbon 0.15, nickel 80.0, chromium 13.0, iron 7.0%) was also tested for this purpose, in view of the extensive experience already available in fabrication of the alloy and of the ease with which good surface quality could be obtained. In service, however, Inconel proved inferior to Nimonic 75, with the result that Nimonic was retained and is still in wide use for this purpose. The severity of the condi-

tions to which flame tubes are subjected has been gradually reduced by improvements in design of the combustion system, this being one of the few cases in which design-development has led to easing of the materials problem.

Air-casings are also made from sheet material, by welding. In this case, temperature conditions are not severe, and although in some cases F.D.P. austenitic nickel-chromium steel has been employed, mild steel sprayed on the outside with aluminium has also been used with success. In Germany, aluminised mild steel has been employed for flame tubes, but even with elaborate air-cooling devices the life of such material is short under the severe conditions involved. Experience has shown that oxidation-resistance and freedom from distortion at the working temperature are the main requirements for flame tubes, and although conditions have been improved by modification in design, there is a limit to what can be done by this means and it is considered likely that the future need for higher gas-temperatures will tax to the utmost the properties of existing materials.

Compressors

The great majority of British gas turbines have employed centrifugal compressors. The double-sided impeller has been made in a high-strength aluminium alloy, and for the first few impellers "RR 56" was used. The material was changed to "RR 59" at the suggestion of the manufacturers of the forging, High Duty Alloys, Ltd., because of its slightly better forging characteristics in large sizes. The nominal percentage composition of RR 59 is: copper, 2.2; magnesium, 1.5; nickel, 1.2; iron, 1.0; silicon, 0.9; titanium, 0.05. This alloy has been used for the major part of the development work, but has recently been superseded by "RR 58," an alloy of similar composition but containing only 0.20% silicon, which has slightly better mechanical properties, particularly at elevated temperatures.

The high-mechanical properties necessary for satisfactory service are obtained by solution treatment and precipitation hardening usual for this type of alloy. The solution treatment temperature is critical and overheating leads to blistering and loss of mechanical strength; quenching is carried out in boiling water with a cold water spray inserted in the centre bore to minimise the stresses set up by the wide variations in the cooling rate.

Testing of Materials for Gas Turbines

The development of the gas-turbine has led to the introduction of some new methods for testing of materials, and has emphasised the importance of certain known methods. In particular, the vital necessity for reliable creep-test methods has been increasingly realised, and such realisation has led to the development of a more systematic basis for comparison of results obtained on different materials, and under varying conditions of test. Increased interest has also been aroused in fatigue-testing at elevated temperatures, while the importance of damping-capacity in gas-turbine design has been recognised, although its full significance has not yet been assessed. In addition to laboratory tests, new types of rig test have been developed for testing finished components prior to assembly. The overspeeding of impellers to about 20% above full speed has been

standard since 1942, and another rig has recently become available for the testing of turbine rotors. Methods for detection of flaws have also been more closely studied. Reference is made to the fluorescent, chalk-and-oil and anodising methods, and to a frequency-of-vibration method developed by Power Jets, Ltd., for inspection of propellers. Supersonic wave methods have also been usefully employed in testing of parts such as stubshaft forgings, which are difficult to examine by X-ray or other methods.

In conclusion, Dr. Taylor made the following suggestions for lines of research which must be followed if the potential usefulness of the gas-turbine is to be fully realised :—

1. Fundamental research on the mechanism of creep and age-hardening phenomena is required, so that it may eventually be possible to design an alloy for a specific purpose, rather than develop it empirically.
2. Further studies are needed of complex stress systems at high temperatures, and of creep-relaxation and recovery phenomena.
3. The development of high-strength ceramic materials

will be important for service under conditions where the limitations of metallic materials become apparent.

4. More information is required about the effects of long periods of stressing at elevated temperatures, on the stability of creep-resisting materials.

5. The use of intercoolers and heat-exchangers is expected to improve considerably the efficiency of the gas-turbine. Little is known so far about the precise conditions of service these components have to withstand, and problems of materials are certain to be encountered. The design of a small but efficient heat-exchanger would contribute particularly to the development of engines of small power.

6. The use of high gas-temperatures to improve efficiency will bring in its train problems of bearing materials and their lubrication. The development of bearing materials which retain their mechanical and bearing properties at much higher temperatures than those in use at present would be very valuable in making elaborate cooling arrangements unnecessary. These in their turn will require new lubricants to withstand the more severe conditions. The silicone resins offer a promising field of development in this respect.

Protection of Zinc Surfaces by Phosphating

New American Methods

ALTHOUGH phosphating as a powerful aid against corrosion has been mainly developed for iron and steel, as the most effective preparation for subsequent painting or varnishing, its application to zinc or galvanised surfaces also figures in the patent literature. The most recent American method is covered by U.S. pat. No. 2394065 in the name of G. W. Jernstedt and J. C. Lum, assignors to the Westinghouse Electric-Corpn., East Pittsburgh, Pa., who now have several interesting phosphating patents to their credit. This last, dating from February 5th, 1946, claims an improved method of forming on a zinc surface a very uniform and finely crystalline coating by the simple expedient of increasing the iron content of the phosphating bath about threefold, that is to say, from the 0.1% hitherto used to 0.3%. And this comparatively high iron content must be maintained by suitable replacement as the bath ages. One proposed means of doing this is to suspend in the solution a canvas bag containing steel wool or iron filings; also by the addition at frequent intervals of hydrogen-reduced iron powder.

A suitable solution therefore contains: Iron not less than 0.3%, zinc phosphate 0.04%, sodium nitrate 0.2-2%, and phosphoric acid sufficient to give a solution having one part free acid to six parts total phosphate. The sodium nitrate is one of the usual so-called accelerators, or oxidising agents for the nascent hydrogen formed. Temperature should be 140°-190° F. As usual, thorough cleaning beforehand is essential by the trichlorethylene vapour or alkaline cleaning, also thorough rinsing after phosphating, preferably with hot chromic acid or chromate solution. Such a zinc-treated surface will be in the

best possible condition for taking a strongly adhesive coat of paint or varnish.

The foregoing method may well be used in conjunction with the activating pre-treatment described in the earlier U.S. pat. No. 2310239, of which the corresponding Eng. pats. are 560847-8, in which are claimed compositions for activating metal and alloy surfaces to facilitate protective coating (phosphating). Briefly, this pre-treatment consists in immersion in aqueous solution of disodium o-phosphate plus a small amount of a titanium compound, the pH of solution being 8-8.5. On such activated surface phosphating can be done very speedily, 30-60 sec., and surfaces which previously were difficult to phosphate will now readily take a coating.

It may be of interest to add that the view previously held that the phosphating business in the U.S.A. was more or less a monopoly under the control of the Parker Rust-proofing Co. is less justified than ever, if, as seems probable, the great Westinghouse concern is entering the field. The Parker company had indeed formed a fairly powerful combine in association with several other firms in the same field; but the most powerful link in this combine—the agreement with the American Chemical Paint Co.—was annulled a few years ago as the result of a suit brought under the Anti-Trust laws. Despite this apparent set-back and the appearance of other competitors, Parker Rustproof Co. still hold the bulk of the phosphating business in the U.S.A. and have several associated companies abroad. For example, both the French and the Dutch associates have now vigorously resumed activity.

The Welding of Light Alloys

A Symposium Presented in Four Technical Sessions

This symposium, organised by the British Welding Research Association, is concerned with some of the work undertaken in the search for stronger light alloys which can be readily welded.

A SYMPOSIUM on the welding of aluminium and magnesium alloys was held in the Henry Jarvis Memorial Room of the Royal Institute of British Architects, on October 16-17, 1946, under the auspices of the British Welding Research Association. It was supported by an Exhibition of practical examples of welds in these alloys and demonstrations of various welding processes at the premises of the Association. That great progress has been made during the war in the science and art of welding the light alloys was apparent to all who visited the Exhibition, particularly to those who were familiar with the difficulties encountered in the initial development and application stages of these alloys.

The symposium was presented in four sessions, at each of which papers on particular aspects of the subject were presented and discussed. In the opening session, at which Sir Arthur Smout occupied the Chair, the development of strong aluminium alloys for welding was considered. In addition to a general introduction to the symposium, given by Mr. A. Ramsey Moon, Director of the British Welding Research Association, Dr. A. G. C. Gwyer introduced the subject of the session, subsequently Mr. E. A. G. Liddiard and Mr. J. Pendleton presented papers for discussion. The subject at the second session, at which Dr. Richard Seligman occupied the Chair, was pressure welding and flash welding of light alloys, which was introduced by Dr. E. G. West. Several papers on the subject were presented by Mr. R. F. Tylecote and a paper on applications of flash welding by Mr. B. Anderson, of Asea Svetsmaskiner, Stockholm, was presented by Mr. A. F. Strachan. Spot welding of light alloys was the subject for discussion at the third session, presided over by Mr. H. J. Pollard, the subject being introduced by Dr. H. Sutton, who also presented a memorandum prepared by LR4 Committee on Spot Welding Procedure. Papers were presented by Mr. F. C. Dowding, Mr. H. Brooks and Mr. T. M. Roberts, and Mr. H. Davies discussed the behaviour of spot-welded structures in the light of investigations carried out by the LE1 Committee on Spot-Welded Structures in Light Alloys. The final session was wholly concerned with magnesium alloys and was presided over by Mr. A. B. Lisle. Mr. W. J. Burling Smith introduced the subject and presented a memorandum on technique for gas welding magnesium alloys prepared by a panel of the LM3 Committee on Fusion Welding of Magnesium-Rich Alloys. Subsequently, papers were presented by Mr. J. Pendleton; Messrs. R. E. Doré, L. C. Percival and R. R. Sillifant; Mr. E. J. Grimwood; Mr. I. H. Hogg; and Mr. F. A. Fox.

An interesting feature of the symposium was that, at each session, after the open discussion and replies by the various authors, there was a general summing-up in addition to the closing remarks of the respective chairmen. In the following notes brief reference is made

to some of the informative papers presented in this symposium.

THE WELDING OF ALUMINIUM-MAGNESIUM ALLOYS.

By E. A. G. LIDDIARD, M.A.

In this paper the author gives a condensed account of the joint investigation by the British Welding Research Association and the British Non-Ferrous Metals Research Association on the welding of aluminium-magnesium alloys. Continuous reference is made to parallel investigations conducted by the latter Association on the casting characteristics of aluminium base alloys and studies of surface reactions between aluminium-magnesium alloys and traces of water vapour. Thus it deals with the background of the problem rather than giving a detailed account of experiments on welding.

The paper briefly reviews the basic considerations which govern the welding characteristics of any alloy, the properties of aluminium-magnesium alloys, factors hindering successful welding, gas content of original metal, porosity developed on heating above the solidus, effect of magnesium content, effect of atmosphere, mechanism of reaction, effect of discontinuities, and the effect of impurities. As a result of work done it has been possible to show how to produce aluminium-magnesium alloy sheet with the minimum tendency to blistering on welding; the requirements are summarised as follows:

1. The metal must be initially free from gas when it is cast. Thorough degassing, preferably with chlorine gas, is therefore essential.
2. The metal must be free from those impurities which favour the reaction with water vapour, and it is important in this connection to avoid the use of flux for degassing and melting which introduces calcium or other reactive elements into the metal.
3. The metal must be cast as sound as possible so that there are no internal discontinuities in the metal when it is finally produced in sheet form.
4. Precautions must be taken to avoid gas pickup during heat-treatment. Precautions necessary include keeping the sheet as dry as possible to prevent adsorption of water vapour on the surface, annealing in atmospheres as far as possible free from water vapour and preferably containing traces of hydrofluoric acid to inhibit the reaction.

In welding, the following precautions need to be taken:

1. The surface of the sheet must be cleaned mechanically immediately before welding, to remove any oxide film and the relatively large amounts of moisture associated with this film.
2. The time taken in welding should be as short as practicable, to cut down the time during which the reaction can take place.

ALUMINIUM ALLOYS FOR GAS WELDING WITH SPECIAL REFERENCE TO ALUMINIUM- SILICON-COPPER ALLOYS.

By J. PENDLETON and E. A. G. LIDDIARD.

The welding behaviour of aluminium, Duralumin and aluminium-magnesium alloys is discussed and some experimental work on aluminium-silicon and aluminium-copper alloys is reported, showing how the behaviour of these materials in welding is related to their casting and heat-treatment characteristics. The report is, however, mainly concerned with the welding behaviour of aluminium-silicon-copper alloys which show promise of good weldability with moderately high strength. A comparison is made with the welding behaviour of aluminium alloys containing from 2.5% to 5% of copper and 5% or 10% of silicon, with and without the impurities normally associated with commercial purity aluminium and with secondary aluminium alloys, and the welding behaviour of other aluminium alloys.

Aluminium-silicon-copper alloys were hot-rolled to sheet and when welded in the solution-treated condition gave weld strengths of 12 to 16 tons/sq. in. with basis metal strengths of from 16 to 23 tons/sq. in. With a copper content of approximately 2.5% and in the absence of impurities, particularly magnesium, in the basis metal, there was no heat-affected zone adjacent to the weld. This has been shown to be due to the relatively sluggish response of these alloys to ageing. The presence of magnesium in the basis metal, however, brings about a marked response to ageing and causes a heat-affected zone to appear in the basis metal near the weld.

The aluminium-silicon-copper alloys investigated show promise as a moderate strength constructional material with good welding characteristics.

PRESSURE WELDING OF LIGHT ALLOYS WITHOUT FUSION.

By R. F. TYLECOTE, M.A., M.Sc., A.I.M.

An essential characteristic of fusion welding is that some part of the metal in the joint is in the cast condition. This is particularly undesirable in the case of some light alloys such as Duralumin, which have poor mechanical properties in this condition. Not only are the properties of the cast zone poor, but there will be an "overheated" zone in which melting of the grain boundary constituents has occurred, and an annealed zone. In this paper are given the results of work undertaken by a Joint Committee on Recrystallisation Welding, and carried out by the British Non-Ferrous Metals Research Association, to determine under what conditions welds could be made in a range of light alloys by the application of heat and pressure at temperatures below their melting points.

Nine aluminium-rich and three magnesium-rich alloys were investigated and it was found possible to weld overlapping sheets in this way to a greater or lesser degree with all the alloys. An aluminium alloy containing magnesium and silicon in the proportions to give Mg_2Si , a Duralumin type alloy, and an aluminium alloy containing 1.25% manganese, were found to give the best results. Great importance is attached to the effective cleaning of the surfaces. Although recrystallisation had occurred across the interface in many cases it cannot be said that microscopically visible recrystallisation is a necessary condition for successful welding.

It is suggested that this method of welding could be applied with advantage commercially to components

having a considerable amount of welding in relation to their size, and that these could be welded in a heavy press with heated dies.

THE PRESSURE WELDING OF LIGHT ALLOY BAR WITHOUT FUSION.

By R. F. TYLECOTE, M.A., M.Sc., A.I.M.

A further investigation on the welding of a light alloy sheet by the simultaneous application of heat and pressure at temperatures below their melting point was undertaken to determine the strength of pressure welds in direct tension. The method used entails the welding of bar, by applying a relatively high initial butting pressure, heating by means of a multi-nozzle oxy-acetylene ring, and applying an upsetting pressure when the required temperature has been reached.

A selection of aluminium and magnesium alloys were used, representative of the range of alloys available, including a Duralumin type of alloy, an Mg_2Si type alloy containing a small percentage of copper, an aluminium-manganese alloy, and aluminium-7% magnesium alloy, the high strength aluminium-zinc-magnesium-copper alloy, and two magnesium base alloys. The results of the investigations on these materials show that the process of pressure welding, outlined by Mr. Tylecote in his previous report, can be applied to the welding of extrusions and other sections in light alloys. All the alloys investigated are weldable with a varying degree of efficiency, although the non-heat-treatable aluminium-manganese and aluminium-7% magnesium alloys appear to give the highest weld efficiency and best values for elongation.

The process can best be applied to the welding of large areas with moderate thickness. In this field, flash welding is at a disadvantage owing to the exceptionally high welding currents that are required. Pressure welding also has a field of application in the making of high quality welds on smaller areas with less expensive equipment.

THE PRESSURE WELDING OF ALUMINIUM ALLOYS.

By R. F. TYLECOTE, M.A., M.Sc., A.I.M.

This is a development report on the subject by the British Non-Ferrous Metals Research Association which discusses the general principles and summarises the practical information obtained on a laboratory scale in this section as a result of the work involved in the previous investigations. It is concerned with the technique employed in applying the process and deals with surface condition, welding temperature and pressure, and welding time; the alloys suitable for pressure welding and the strength of welds obtained. Examples of pressure welding applications are given, together with details of the technique from which information is obtained of the design of tools and equipment used in preparing pressure welds in the laboratory.

EXAMINATION OF LIGHT-ALLOY FLASH WELDS MADE BY ASEA SVETSMASKINER.

The welds examined had been made in Sweden on materials supplied by the British Welding Research Association. The welding process used is described in a report by Dr. M. S. Fisher entitled "ASEA Automatic Flash Welding Machines" (LR 5/2). The object in

examining the welds was to determine their tensile properties and also whether welding occurred by fusion or by pressure.

Thirty-nine welds were supplied made from seven different materials. The materials tested and the test methods employed are tabulated and the welds were hardness and macro-examined. As a result of the examination, the theory is advanced that these welds are flash welds in which the conditions of flashing have only been sufficient to produce a small amount of molten metal at the centre. The upsetting pressure has extruded this molten portion to the outside regions of the weld, at the same time "Wetting" the surrounding surfaces. In some cases these surfaces have been heated to incipient fusion temperature either previously (by flashing) or by contact with the fused metal, and the subsequent flow of liquid metal over the surface removes the oxide film. In other cases where the internal surfaces have not been heated to incipient fusion temperature, some oxide remains and is evidenced by sharp dividing lines between the fused metal and the parent metal, broken to a greater or lesser extent by integrating crystals.

This theory accounts for "interfacial" fractures and the discontinuities obtained in some of the welds in the tensile tests.

INDUSTRIAL PRACTICE FOR SPOT-WELDING LIGHT ALLOYS.

This is a memorandum which has been prepared by the LR 4 Committee on Spot-Welding Procedure for Light Alloys and is at an interim stage. It deals with the machines used for spot-welding light alloys and gives typical examples of settings. Reference is made to machine maintenance; the need for a maintenance schedule is emphasised to maintain primary and secondary connections, contactor surfaces, limit switches, air supply, water-cooling parts and moving parts. The importance of surface preparation is indicated and pickling solutions recommended for aluminium base alloys are given together with surface treatments for Duralumin type alloy. All methods of surface preparation aim at providing a surface of uniform electrical resistance, and the most direct method of checking is by measurement of contact resistance, which is discussed. Other important aspects discussed concern the electrodes; methods of assembly; inspection control and metallurgical control.

METHODS OF SURFACE PREPARATION OF LIGHT ALLOY FOR SPOT WELDING.

More specific details are given in this progress report of the LR 3 Committee on surface preparation. The condition of light-alloy sheet prior to spot welding is of vital importance to the ultimate quality of the spot welds. The strength of the weld is directly proportional to its size, and this in turn is related to the heat input which goes to the making of the weld. The energy required to make a weld is proportional to $I^2 RT$, where I is the secondary current, R is the resistance between the electrodes, and T is the weld time. It is obvious that the resistance between the sheets and the resistance between the electrodes and the sheet are important factors in the overall electrode to electrode resistance, and these resistances are governed by the method of surface preparation. In the making of a spot weld it is essential that the sheet-to-sheet resistance is kept constant to ensure uniform strength of weld, and

it is also desirable to reduce the electrode-to-sheet resistance to as low a value as possible. In this way, the heat can be located between the sheets where it is used to make the weld and not between the electrode and sheet, where any heat would lead to alloying of the work and electrode materials, leading to excessive pick-up and too-frequent cleaning.

Investigations on the various aspects of cleaning are briefly described and recommendations are made as a result of the work done.

SPOT WELDING OF SOME ALUMINIUM AND MAGNESIUM ALLOYS.

By H. BROOKS, B.Sc., A.I.M.

This paper summarises a number of reports on investigations carried out by members of the LR 1 Committee of the British Welding Research Association on the above subject. The alloys investigated included two non-heat-treatable aluminium-base alloys, an aluminium-coated Duralumin alloy and two magnesium base alloys.

The two non-heat-treatable alloys investigated were the MG 5 and MG 7 aluminium-magnesium alloys which are considered the strongest of the aluminium-base sheet alloys which do not require heat-treatment. It was concluded that welds made in these alloys can have static shear strengths, strength consistencies and shear fatigue strengths as high as those of good welds in Alclad or Duralumin. Alclad is the material most extensively used in aircraft construction and an investigation on the welding of Alclad panels on a condenser-discharge machine is described which showed that high standards of weld strength and consistency are obtainable. Attention is given to the detection of cracks in spot welds in Alclad and an investigation by Dr. M. S. Fisher is cited in which the methods available for detecting these internal cracks are compared.

Another investigation referred to concerns tests made to determine the spot-welding characteristics of two magnesium-base alloys: one containing about 1.5% manganese, and the other a higher strength alloy containing about 6% aluminium. The surface preparation and the subsequent testing technique of the welds are described.

SPOT WELDING IN LIGHT ALLOYS: PRESENT TRENDS IN AMERICAN MACHINE DESIGN.

By T. M. ROBERTS.

Welding machine manufacturers in this country have, in the past, shown little interest in the obvious need for machines possessing reasonably high operating speeds. On the other hand, most American light-alloy spot machines of recent years are capable of being operated at 80-120 spots per minute, some as high as 200 spots per minute, and various operators have been timed at around 80 spots per minute. In this country it has been inferred that machine operators cannot make use of welding speeds in excess of 40 spots per minute. It is true that any appreciable increase in machine operating speed, will not affect the average output in direct proportion, but some gain is realised and on easily handled assemblies the increased output can be quite considerable. This paper deals primarily with light-alloy spot welding in the U.S.A. as surveyed during the summer of 1945. In the main it is restricted to a description of the types of machines in use or available during that period.

TECHNIQUE FOR THE GAS WELDING OF MAGNESIUM ALLOYS.

This memorandum has been prepared by a panel of the LM 3 Committee on Fusion Welding of Magnesium-rich Alloys of the British Welding Research Association. It was issued in May of this year and contains basic information relating to the welding of magnesium. In its 38 pages it deals with the properties of magnesium affecting welding technique; effect of composition of the alloy on welding behaviour; the welding flame; flux; welding rods; design; edge preparation; setting up; manipulation; finishing and protective treatment; weld defects; inspection and testing; testing of welds; and carries an appendix giving details of chromating treatments.

THE TENSILE STRENGTH OF GAS WELDS IN MAGNESIUM-MANGANESE ALLOY TO SPECIFICATION DTD 118.

By J. PENDLETON, B.ENG.

The wrought magnesium alloy most commonly welded at the present time is that containing about 1.5% manganese, as defined by specifications DTD 118 (sheet) and DTD 142 (bars and sections). The alloy is readily gas welded, but it is general experience that the tensile strength of specimens cut from welds varies over a relatively wide range, e.g., from as low as 6 to a maximum of about 14 tons/sq. in., compared with the A.I.D. requirements of 8 tons/sq. in. The present report is mainly concerned with a study of the causes of this inconsistency. It describes work carried out by the British Non-Ferrous Metals Research Association for the LM 3 Committee of the British Welding Research Association.

From the results of his experimental work the author concludes that the tensile strength is related to the grain size of the basis metal immediately adjacent to the weld, and the most important factor determining this grain size is time of treatment at elevated temperature during welding. Operations, such as tacking and restarting, which increase this time, result in abnormally large grain sizes and correspondingly low strengths. It was found that small additions of calcium or cerium limited this grain growth so that tacking and restarting did not cause low strengths, but alloys containing these additions proved unsuitable on account of a tendency to crack on welding.

The tensile strength of gas welds in magnesium—1.5% manganese alloy sheet—has been further examined to confirm, or otherwise, the findings given in the earlier report referred to above, that abnormal grain growth in the basis metal adjoining the weld is responsible for marked reductions in strength. This finding appeared to be inconsistent with the experience of other investigators who had examined the problem of scatter in tensile strength values for welds made under industrial conditions.

In the present series of tests attention was given to several points of difference in the technique used in making and testing the welds made industrially and in the laboratory respectively.

The results show that three of these differences explain the discrepancy:—

(a) The laboratory welds were made in jigs and were thereby substantially free from misalignment while the industrial welds were not.

(b) The laboratory welded test pieces subjected to tensile test were only 0.5 in. wide, while the industrially welded test pieces were 1 in. wide, with the result that the former were more seriously affected by local areas of abnormal grain growth.

(c) The industrial operator's welding speed in making tacks and restarts was sometimes but not always higher than that used in the laboratory, with the result that the degree of abnormal grain growth at tacks and restarts was sometimes less than that observed in the laboratory welds.

Thus welds made between accurately aligned sheets by the industrial operator, in most cases, but not always, showed marked grain growth at tacks and restarts and this grain growth resulted in a reduction in strength comparable with that earlier observed in the laboratory welds (making due allowance for the wider test pieces machined from the industrial welds).

Plant for Metallurgical Industries

In the engineering industry of Great Britain, as in many other fields of applied science and technology, there have been great developments and advances during these past six years of war, and it is fitting that this new knowledge and experience should be used in the broadest way for world recovery, and the equipment and restoration of industry. With this in view The Wellman Smith Owen Engineering Corporation, Ltd., Victoria Street, London, S.W. 1, have recently published a brochure, which indicates in outline only, the types of equipment this organisation is now able to offer.

This publication, which is referred to as an "Export Brochure," is of an outstanding character, and is quite novel in its general arrangement and presentation. The text, describing the main types of equipment designed and built by this organisation, is printed in four languages—English, Russian, French, and Spanish—in the form of fly-leaves opposite their appropriate illustrations, with colour according to language. The illustrations are in colour, and the whole is very pleasing in addition to being informative. The department, within the organisation, responsible for the design and compilation of this brochure is deserving of every credit for this very worthy production in which the printer has contributed in no small degree.

We understand that this brochure is being distributed with the two-fold object of reviving pre-war overseas connections, and of making Wellman products known in those new markets which now present such a promising field for British engineering. Readers at home and overseas interested in engineering equipment of diverse types not only for the steel-producing and general metallurgical industries, but for special material handling projects, will find this brochure unique of its kind and of great interest.

MR. CHARLES R. KNAGGS has retired from the position of pig iron salesman and ore buyer with Dorman, Long & Co., Ltd., after more than 55 years with the Company. His record is unique in that the whole of his business life has been spent in one building—the present Dorman Long offices in Zetland Road, Middlesbrough. Mr. Knaggs is recognised as an expert in the selection and handling of foreign ores for blast furnace and possesses an unrivalled knowledge of the pig iron trade, especially in relation to the warrant market,

Technics of Soviet Iron and Steel Industry

By Academician I. Bardin

It is probable that the Soviet iron and steel industry suffered more damage, as a result of the war, than that of any other country involved. The majority of her plant was relatively new and much of it was situated in districts invaded by the Germans and subsequently wrecked. The author indicates the efforts being made to reconstruct the various plants, on the lines of a new five-year plan, which will incorporate more recent developments and enable pre-war production to be greatly exceeded. A general picture of reconstruction is given.

THE Soviet steel and iron industry, radically reconstructed in the course of the first three five-year plans, will play as decisive a part in the forthcoming new development of the entire economy of the Soviet Union as it did before the war. The Law on the "Five-Year Plan for the Reconstruction and Development of the National Economy of the U.S.S.R. in 1940-1950," passed by the first session of the Supreme Council of the U.S.S.R., provides for an increase in the annual output of pig-iron, steel and rolled-steel by approximately 35% in 1950, as compared with the last pre-war year (1940).

This increase, very significant in itself, is the more striking if we take into account the deep wounds inflicted by the German invaders on the ferrous metallurgy industry. The Nazis wrecked 37 steel and iron works and fully or partly destroyed 62 blast furnaces, 213 open-hearth furnaces and 248 rolling mills. These must be reconstructed and modernised. 22 wrecked blast furnaces, 59 open-hearth furnaces and 39 rolling mills have already been reconstructed and put in operation through the efforts of Soviet scientists, engineers, technicians, building workers and metallurgists. But this is only the beginning. The new five-year plan provides for the introduction of large quantities of various equipment, in many cases much more powerful than that with which the works were fitted before the war. This equipment includes 45 blast furnaces, 165 open-hearth furnaces, 15 Bessemer and Thomas converters, 90 electric furnaces and 104 rolling mills.

The erection and putting into operation of this plant will increase the output in the course of the coming five years, but a considerable part of the increase will be achieved as a result of improving the technological processes, increasing the productivity of the old equipment and further mechanising laborious processes. Modernisation of the equipment and perfection of the productive processes form the principal link in the new five-year plan for the steel and iron industry.

One of the first aims is to more fully and economically utilise the raw materials and fuel, and improve the methods of prospecting, mining and concentrating of all minerals used in metallurgical production. Thus, in prospecting for iron ores, geo-physical methods and the use of new, powerful, up-to-date equipment—high-speed boring equipment and machinery on trailers—will play a big part.

Iron and manganese ores and minerals (limestone, dolomite, fire-proof clay, magnesite) will be mined by

new methods, considerably extending the scale of mining with minimum losses. For example, the system of ore caving and shrinkage stopping will be employed in the Krivorozhski basin, and the mineral pillar working system in the Chiaturi manganese-ore deposits. All mining and transportation of the ore both underground and above the surface will be extensively mechanised.

Thorough preparation of the raw materials plays an important part in the increase of the productivity of blast furnaces. For this purpose the ores will be sorted at the mines not only as regards their chemical composition, but also their size, followed by mixing the ores in ore-mixing plants at the steel and iron works in order to obtain the required composition.

Since pig-iron will essentially be smelted in powerful blast furnaces with a useful volume of 1,000 and 1,300 m.³ and a height of 28.5 and 31 m. respectively, this will necessitate the briquetting of mine and furnace top dust. For this reason, provisions are being made to build agglomeration factories at the steel and iron works and the mines. The sorting of coke is being improved in order to load it into the blast furnaces in lumps with a diameter of no less than 40 mm. These measures will result in a considerable economy of ore and coke, and will make it possible to raise the average output of the blast furnaces to what was formerly considered a record output.

The successful results of the laboratory and semi-industrial experiments on direct processing of iron without the blast furnace process make it possible to produce spongy iron, necessary for the production of high-grade special steel, on an industrial scale.

The scientific research and the theoretical and experimental work on the use of blowing, enriched by oxygen, in metallurgical processes will be extended in the course of the five-year plan. The solution of this problem will make it possible to substantially increase the productivity of the existing aggregates.

A whole branch of industry on reprocessing the enormous reserves of metal scrap into quality raw material for steel making is being set up. Big breaking shops in steel and iron works are being fitted out with the latest powerful equipment; shearing machines, cutting torches, electric arc cutters, pig breakers for breaking up pig-iron scrap, travelling cranes for transporting oversize scrap, etc. Mechanisation of loading and unloading at the stock piles of steel mills, and the installation of magnetic cranes, in particular, will enable

the steel mills to release a considerable number of auxiliary workers, who will be more expediently employed in production or on construction.

The capacity of the open-hearth furnaces is being increased in a number of steel and iron works up to 350 tons in a single heat. An accelerated technological process is being introduced and the thermal capacity of the furnaces, equipped with automatic regulation, is being increased. The small and medium open-hearth furnaces (up to 100 tons) will be used only for production of high-grade steel. This specialisation will result in increased output.

A new technology, which will improve the quality of the metal, is being introduced into the Bessemer shops; this includes automatic control of blowing and dephosphorisation of the steel in the ladles by processing it with synthetic slags and solid mixtures. Incidentally, this method makes it possible to expand the raw material base of the Bessemer converting, and, thus, increase the output of high-grade steel.

The capacity of the electric smelting furnaces, which will specialise in production of high-grade alloy steel, is being considerably increased. Production of rolled steel must be radically modified in order to more fully meet the requirements of the different branches of national economy. Production of many new varieties of metal will be launched during the new five-year plan. These include new sections of structural steel, wheel profiles, wide sheet and strip, and special sections for automobile building, new types of heavy rails and railway couplings, cold-rolled transformer steel, many grades of steel with special physical properties for radio-technics, instrument manufacture, automatic machinery, precision steel tubes, thin-walled tubes for the navy and air force.

In order to ensure the high quality of rolled steel, the rolling mill shops of the steel and iron works are being fitted out with the most up-to-date equipment. The technological processes are being substantially modified. Continuous and semi-continuous processes, high-production rolling mills—claimed to be the most perfect in the world—are being installed in the new shops. Cold-rolling of steel strip and its production in rolls is being considerably developed. A new method of continuous automatic welding, which had justified itself in practice during the war, as well as electric welding by means of an electric-welding aggregate, which performs several consecutive operations, will be used in production of welded steel tubes. Centrifugal casting will be extensively used in production of cast-iron pipes.

Mechanisation of the principal and auxiliary operations in steel mills is of great importance. The fourth five-year plan provides for the most extensive mechanisation of production, which will not only facilitate the work and reduce the number of auxiliary workers, but will, primarily, make it possible to speed up the delivery and feeding of raw materials, the removal of the finished products and scrap, which means that it will, in the final analysis, increase the production of metal.

The process of mastering the most modern technics of steel and iron production will be based on the corresponding development of scientific research work. Soviet scientists have made an invaluable contribution to the solution of a number of problems in the process of planning and building new steel and iron works,

developing new technological processes and organising new production.

This scientific research work will be continued on a considerably larger scale in the course of the new five-year plan. The Institute of Metallurgy of the U.S.S.R. Academy of Sciences and the Institutes of the Ministry for Ferrous Metallurgy play the leading rôle in this work.

Expansion in Structural Engineering

IMPORTANT extensions to the main structural engineering shops of Dorman, Long & Co., Ltd., in Middlesbrough, are being undertaken to facilitate the handling and fabrication of the exceptional tonnages of structural steelwork which the Company has on order for home and export.

The area of the existing shops, already much the largest in Great Britain, is being increased by over 110,000 sq. ft. at a cost of approximately £120,000. The extensions will be equipped with new and up-to-date handling devices to ensure the even flow of material and enable the output of fabricated steel from these shops to be increased by about 20%.

At the present time, very large tonnages of structural steelwork for twelve power stations, some of which are of exceptional size and capacity, are being handled. With the additional facilities now being provided, larger and heavier constructional steel units than have yet been fabricated in this country can be undertaken. In addition to the heavy structural steelwork, very large tonnages of lighter structural work are also passing through the shops. At the same time an important contract for 10,000 all-welded railway wagon bodies for the home railways is in mass production.

Revision of Prices of Raw and Fabricated Aluminium Products

OWING to the increase in the price of virgin aluminium, which became effective on September 9 last, and to further increases in production costs which have taken place during recent months, the British Aluminium Co., Ltd. announce that prices of raw and fabricated aluminium products have had to be adjusted. New prices apply to all materials dispatched on and after the dates given below.

Raw Material Products. Virgin aluminium alloy ingots, virgin aluminium hardeners, pure aluminium and aluminium slabs, extrusion billets and wire-bars, on and after September, 16, 1946.

Fabricated Aluminium Products. Sheet, coiled strip and circles, extrusions, drawn sections, tubing and wire, hot-rolled rod, slugs, etc., in pure aluminium, aluminium-manganese (BA. 60) alloy and certain other alloys, on and after October 14, 1946.

Prices for extrusions, tubing and wire have now been logically related to present-day fabricating facilities and production costs in a similar manner to prices for sheet, coiled strip and circles introduced in March last. Except for the change corresponding to the reduction in price of virgin aluminium in 1945, prices for these materials had not been adjusted to conform with increasing production costs since 1940.

With the new price structure for all standard products, users of aluminium are advised to order materials in the largest possible quantities to take full advantage of minimum prices and discounts.

A t
of the
tribute
Mr. W
leaders
during
of this
addition
Council
aegis o
Weldin
stitutio
to meet
The
Dyson,
progress
sight o
of the
be told
but the
sceptic
and it
called
facture
occasio
Whi
would
he em
rather
Council
recent
attain
grades
definit
scienti
the ste
spread
and i
empha
the br
that th
the res
contra
cerned
bodies
In
Mr. A
Weldin
that S
weldin
meetin
first-h
Ameri
Mr.
Counc
part p
of 191
the re

The Institute of Welding

Expansion of Scope and Activities

AT the recent general meeting of the above Institute held in London, the President, Mr. Arthur Dyson, M.Inst.C.E., gave an address on the expansion of the Institute's scope and activities. He first paid tribute to the high standard set by his predecessor, Mr. W. W. Watt, and of his forceful and far-sighted leadership. It is noteworthy that in the two years during which Mr. Watt was in office, the membership of this Institute increased from 3,252 to 5,115; in addition, under his guidance the Welding Research Council, which had reached its maturity under the aegis of the Institute, was transformed into the British Welding Research Association, and the whole constitution of the Institute was recast and reconstructed to meet the demands of the post-war situation.

The outlook for welding in this country, said Mr. Dyson, is a very bright one. In spite of the astonishing progress made during the war, we are not yet within sight of exhausting the possibilities for the employment of the various welding processes. There is still much to be told about the part welding played during wartime, but the lessons have been learned by thousands whose scepticism and inertia long hindered its development, and it is confidently expected that welding will be called upon to contribute more and more to the manufacture of everything made of metal, and, as we are occasionally reminded, of things made in plastics.

While he had no doubt that the number of members would be greatly increased during the next few years, he emphasised that it is the quality of membership rather than number that will count, and thought the Council had made a wise and far-seeing decision in the recent revision of the membership regulations. To attain the status of the older Institutions, the several grades of membership of this Institute must stand for definite and ascertainable degrees of technical and scientific accomplishment. He went on to describe the steps contemplated and taken by the Institute to spread technical knowledge, of its educational policy, and its various services to members. Particular emphasis was given to the important part played by the branches. But Mr. Dyson was equally emphatic that the Institute must not be content merely to enlist the resources and energies of its own members; on the contrary, it must seek contact with all who are concerned with welding, and form links with all associated bodies.

In concluding his address, Mr. Dyson welcomed Mr. A. C. Weigel, a past president of the American Welding Society, and referred to the great contributions that Society had made to the science and practice of welding. He called upon Mr. Weigel to address the meeting, so that members would be able to learn at first-hand something of the plans and objectives of the American Welding Society.

Mr. Weigel, who is Director of the Welding Research Council of the United States, began by referring to the part played by welding in the recent war. In the war of 1914-1918 welding was used to a limited extent; in the recent war, however, it played an important part

in the construction of fighting ships, merchant ships, aircraft, armaments and all types of military supplies. Both countries can be proud that they were leaders in the development of the art. He reminded members that the first coated welding rod was of British manufacture.

For many years, continued Mr. Weigel, our young men in colleges have been learning how to joint material by riveting and bolting, with only a statement in their notebooks that welding can also be used; no information is given on the need for modifying a design for welding to provide a satisfactory job, and no mention is made of the advantages obtained by radiography and subsequent heat-treatments. A programme has now been prepared by the Educational Committee of the American Society to supply information to the authors and publishers of machine design, structures and other technical books used in colleges.

The most important work being carried on in conjunction with the American Welding Society is the work of the Welding Research Council of the Engineering Foundation. Undoubtedly, the greater part of welding research is done under the auspices of private corporations, and essentially for their own benefit. But, most progressive companies have learned that, as soon as a particular piece of research reaches a state of perfection or completion it is profitable to divulge the information. For the most part, however, this research work is made to improve the materials, methods of fabrication, and end products, or overcome difficulties, and to achieve lower costs. The Welding Research Council has encouraged the prompt and broad dissemination of this information.

During the war a great deal of research work dealt with the welding of armour plate, tanks, ships, planes, and the welding of ordnance material generally. A number of investigations were concerned with the development of special electrodes for the conservation of strategic materials. With the cessation of hostilities Governmental research in the welding field came to an end, with the exception of work relating to ship construction.

Co-operative research in the welding field in the United States before the war was largely conducted under the auspices of the Welding Research Council, which is actually the welding research organisation of the various engineering societies of that country. Starting with an initial grant of \$7,000 from the Engineering Foundation, the budget of the Council for the past several years has been of the order of \$250,000 annually; the greater part of these contributed funds has been earmarked for specific research projects.

Although at first most investigations were aimed at furnishing engineering and design data badly needed by code-making bodies of either the American Welding Society or other engineering societies, the trend has been decidedly towards fundamental research. Two examples were given to indicate the reason for this trend. In one case it was found necessary to limit the carbon and manganese content of steel used in bridge construction

to 0.25% carbon and 1% manganese. Objections were raised, and an investigation was started over a whole range of carbon and manganese in plain carbon steels. After preliminary work had been done, it became apparent that a more fundamental approach was needed. The other case concerned weld-stress investigations, designed with the object of determining means of measuring and controlling residual welding stresses, and in finding out what happened to them in service.

The Geology and Mineral Resources of British Guiana

IN the fourth of the series of lectures on the mineral resources of the Colonies, organised by the Imperial Institute, Mr. S. Bracewell, Director of the Geological Survey of British Guiana, dealt in turn with the physical and geological features of the Colony, its mineral resources and mining industries, and the history and methods of geological investigations.

The Colony, about equal in area to Great Britain, has considerable variety of physical features. The low coastal plain, protected from the sea by mangrove swamps or sea walls, supports sugar and rice cultivation. Inland lies the White Sand Region with forests of valuable hardwoods intersected by navigable rivers. The Pakaraima Mountains form a western rampart to the Colony, culminating in the great Mount Roraima, and famous for the Kaieteur Fall and other spectacular gorges and cascades. To the south lie the savannahs with cattle ranches and wide uninhabited areas.

Several geological groups are recognised. The youngest are the alluvial and residual deposits from which most of the gold, diamond and bauxite production is obtained and the Coastal Sedimentary or White Sand Series which have been prospected for petroleum. Older, but of uncertain age, are the Kaieteurian Sedimentary Series, from which many of the diamonds may have been derived, and the Newer Basic Intrusives. The Crystalline Basement includes the Volcanic Series, Acid and Basic Intrusives, and the oldest Gneiss-Schist Complex, and is of great economic importance, since both the gold and bauxite deposits have apparently been derived from it.

Since 1884 some £32,000,000 worth of minerals were produced and exported from the Colony, an average of more than £500,000 per annum. Of this total gold accounts for more than £12,000,000. The bulk of this gold has been recovered from small alluvial workings, but it seems likely that the future of the gold industry will depend more upon the development of dredging and organised deep mining enterprises. Considerable interest is now being shown in the gold potentialities of the Colony.

Between 1917 and 1945 more than 9,000,000 tons of high-grade bauxite, valued at £11,500,000 were exported. During the war, when aluminium production was vital and European sources of bauxite fell under enemy control, bauxite production was increased fourfold, from 476,000 tons in 1939 to 1,901,000 tons in 1943. Over 6,000,000 tons of bauxite were exported from the Colony during the war.

Diamonds valued at £8,500,000 were produced between 1901 and 1945. Production has declined steadily since 1923, when 214,385 carats valued at £1,000,000 were recovered. Most of the production has come from small alluvial workings. Mr. Bracewell considers that the

In spite of the large volume of research work that has been carried out in the last decade, a great deal remains to be done. The flow and fracture of metals is not yet understood. Current researches in the field of non-destructive tests for welds will bear fruit and will benefit the entire metal-fabricating industry. Improved steels, heat-treatments, and, similarly, improved methods of welding, are confidently expected as a result of additional research work.

future of the diamond industry is dependent upon the possibility of the introduction of more organised methods of exploitation and the possibility of dredging the alluvial deposits in the larger rivers.

A number of other minerals are known in British Guiana which may prove to be of economic value in the future, and much prospecting remains to be done. It has been suggested that petroleum may occur off the coast of the Colony, possibly at a considerable distance from the shore, but where the sea is still relatively shallow.

In reviewing the history and methods of geological investigations, Mr. Bracewell urged the need of maintaining an appropriate balance between reconnaissance and systematic surveys and petrological work on the one hand, and *ad hoc* investigations with a more definite short-term economic objective on the other.

Forthcoming Meetings

INSTITUTION OF ENGINEERS AND SHIPBUILDERS IN SCOTLAND.

Oct. 22. "Powdered Metals and the Engineer," by H. W. Greenwood.

WEST OF SCOTLAND IRON AND STEEL INSTITUTE.

Nov. 8. Discussion on Surface Hardening.

INSTITUTE OF WELDING. WEST OF SCOTLAND BRANCH.

Nov. 13. "Production Control of Welding in Shipbuilding," by D. M. Kerr.

SHEFFIELD AND DISTRICT BRANCH.

Nov. 7. "Welded Structures," by S. B. Rippon.

THE INSTITUTE OF METALS. LONDON LOCAL SECTION.

Nov. 14. "Metallurgical Education," by Professor D. Hanson, D.Sc.

SHEFFIELD METALLURGICAL ASSOCIATION.

Oct. 29. Paper by Dr. J. W. Jenkin.

Nov. 19. "Statistical Analysis of Steel-making Data," by N. H. Bacon.

MANCHESTER METALLURGICAL ASSOCIATION.

Oct. 23. "The Electron Microscope as an Aid to Metallurgy," by Dr. S. J. Kennett.

Nov. 6. "Modern Non-Ferrous Foundry Control," by W. A. Baker, B.Sc.

INSTITUTE OF BRITISH FOUNDRYMEN. SHEFFIELD BRANCH.

Nov. 11. "X-Ray Technique in the Examination of Steel Castings," by Dr. R. Jackson.

SPECIALLOID LIMITED have been appointed sole export distributors for all world markets, except for Eire and the Union of South Africa, for "Hagco" cylinder liners, valves, valve guides and valve seats manufactured by Harold Andrews Grinding Co., Ltd., of Birmingham. It is intended to market these parts through the existing Specialloid overseas distributing organisation. This company also distributes the products of Glacier Metal Co., Ltd., in the Export Market.

British Steel Founders Association Convention

The first technical Convention held by the above Association proved a great success; the attendance and liveliness of the discussions indicate that the steel casting industry has every intention of being in the vanguard of development in the years to come. The work of its technologists and metallurgists will be actively directed to greatly expanding the range of purpose for which carbon and alloy steel castings will be available. It is only possible here to give a brief outline of this meeting.

THE first technical Convention of the recently formed British Steel Founders Association, held at the Royal Victoria Station Hotel, Sheffield, on October 3-5 inclusive, proved a great success. A reception and an inaugural dinner preceded the more technical part of the Convention, which were attended by the Lord Mayor, the Master Cutter and other distinguished guests. The following day visits were arranged to neighbouring works, including: Messrs. David Brown and Sons, Ltd., Messrs. Edgar Allen and Co., Ltd., The English Steel Corporation, Ltd., Messrs. Firth-Vickers Stainless Steels, Ltd., Messrs. Hadfields, Ltd., Messrs. Samuel Osborn and Co., Ltd., and Messrs. Wm. Jessop and Sons, Ltd. At 4-30 in the afternoon there was a reception at the Town Hall by the Lord Mayor of Sheffield, Alderman C. W. Gascoigne, J.P.

Chairman's Address



Mr. Charles S. Hill.

In his address, the Chairman of the Association, Mr. Charles S. Hill, said the formation of this technical association was the logical outcome of a gradual change in the outlook of managements from a strict isolationism in the matter of divulging their methods or opening their shops to visitors, to a point of view that recognised the futility of such secrecy, and that any advantages gained from a few more or less exclusive methods, were more than

offset by the resulting ignorance as to the methods of their competitors. Such a state of affairs is liable to engender an unwarranted complacency and absence of self criticism that stultified real progress.

During the first world war, chinks appeared in the "iron curtains" that had surrounded many foundries up to that date, and between the wars a number of foundries were more and more ready to exchange information and assistance with their competitors. During the last war, however, the curtains were thrown right back and the benefits experienced from the unrestricted exchange of information that took place, particularly among those dealing with bombs and tank castings, was so marked that little, if any, opposition was encountered to the setting up of the organisation, and the encouragement and support that has since been given by the indus-

try is well illustrated by the gratifying attendance at this Convention.

The design of the organisation that would best further this drive to efficiency was, naturally, given much thought in the light of the objects in view, which may be classified as follows:—

1. The fullest possible co-operation and discussion on their common problems between the maximum number of individuals.
2. Surveys of the plant used, and its difficulties and weaknesses.
3. Management problems, such as maintenance, planning, ratefixing, etc.
4. Surveys of the day-to-day technical problems of all kinds associated with pattern-making, moulding, steel-making, running, heading and dressing and, in addition, good house-keeping.
5. Controlled experiments to elucidate points of importance brought to light by the surveys mentioned.

All the activities mentioned are within the province of the Regional Committees, as the Main Technical Committee is merely there to co-ordinate and direct the work, and to be the means whereby outside scientific and technical assistance may be obtained. Up to the present time, much work of the kind mentioned under the first three headings has occupied the Regional Committees; and several preliminary surveys have been completed, so that the absence of satisfactory arrangements whereby the main committee could call on outside technical and scientific assistance, while restricting our activities, has not been too serious.

Technical Sessions

Three technical sessions were held, the first a round-table discussion on sand practice current in the Lancashire and Yorkshire region, which was introduced by Mr. R. S. Pratt, with a commentary by Mr. T. R. Walker; the second was a discussion on the relationship between temperature and fluidity in converter and electric steels, introduced by Mr. L. W. Sanders; and at the third session Mr. Basil Gray dealt with the origin and activities of the British Steel Founders Association Main Technical Committee, which was followed by a discussion on the past and future operations of the Committee.

Sand Practice Current in the Lancashire and Yorkshire Region

In introducing the subject Mr. R. S. Pratt referred to the wide divergence in the types and properties of moulding materials employed, the reasons for which were not difficult to trace. Deposits of natural moulding sand vary considerably, not only in different countries

but even in different localities, and transport costs limit the choice. In addition, however, technique varies between foundries, depending upon the type of castings produced, and this, combined with the geographical factor, leads to widespread divergence in sand practice.

The Association considered that the subject warranted detailed investigation and that the knowledge so gained would lead to greater uniformity in moulding sand practice. With this in view an investigation was undertaken to determine the extent of the variation in sand practice within a relatively small area. In the first place this investigation took the form of a questionnaire to all members in the Lancashire and Yorkshire region. The resulting data was assessed and analysed, as far as possible, by a panel of the Lancashire and Yorkshire Regional Technical Committee of the Association, and four interim reports have been issued.

The data given in these reports indicated that the divergence in practice was greater than anticipated and the investigation was continued by sending the questionnaire to all members of the Association. After careful consideration, however, it was felt that the importance of the investigation and the complexities which it involved were such as to warrant special treatment before proceeding on a wider basis. With this in view it was thought that the industry as a whole would benefit from a free discussion of the subject.

Relationship Between Temperature and Fluidity in Converter and Electric Steels

Mr. L. W. Sanders introduced the subject and presented a paper by himself and Mr. C. H. Kain dealing with some experiments with a foundry test for the fluidity of molten steel. For many years the authors had held the view that at the same temperature there is relatively little difference in fluidity between converter and basic electric steel. Data published in 1938 showed that in the foundry with which the authors are associated, converter steel was consistently 20° – 30° C. hotter than electric steel when poured under the same ladle conditions. It was also shown that the rate of loss of temperature on both types of steel was the same, which appeared to disprove the suggestion that converter steel had better life owing to exothermic reactions proceeding in the metal. About this time the Ruff test was being used on the electric furnace stage as a control test, but it was not found possible to produce completely accurate correlation between the pouring properties of the steel in the foundry and the fluidity as shown by the Ruff test on the furnace stage.

In addition to the Ruff test various forms of spiral tests are also in common use. Both these types of test are small and primarily suitable for laboratory work and it is considered that a stage test is not a reliable guide to the pouring properties of the steel. In view of the objections to existing fluidity tests the authors designed a practical test piece suitable for use in the foundry and describe tests carried out in their experiments and the results have enabled the authors to conclude that:—

1. Consistently reproducible results may be obtained within narrow limits.
2. Temperature rather than steel-making is the deciding factor in fluidity. There appears to be a marked increase of fluidity at temperatures over $1,580^{\circ}$ C, this change point being more pronounced in converter than in basic electric steel.

3. In basic steel a number of heats of low fluidity occur in the higher temperature ranges, but very few corresponding heats of high fluidity in the lower temperature ranges have been recorded.

In converter steel only two heats of low fluidity occur in the higher temperature range.

4. Analysis of the results shows that in the two carbon ranges—(1) 0.15 – 0.20 , (2) 0.25 – 0.30 —there is on great difference in fluidity.
5. It would be interesting to produce converter steel in a deliberately over-blown condition to see how this condition compares with the alleged over-reduced condition in basic electric steel.
6. It may be argued that the results merely indicate that the correct temperature at which to pour the casting of the design used for test purposes is $1,580^{\circ}$ C. Further tests on various ingate sizes and ingates, bargate and downgate ratios would be interesting.

Considerable discussion of a somewhat lively character took place at each session, but the report of the proceedings just came to hand as we were going to press with this issue and it has only been possible to present an outline of what was a very interesting and informative meeting.

A New Magnetic Filter

A NEW type of magnetic filter has been produced by Philips Industrial (Philips Lamps Ltd.) in which the method of cleaning the filter has been radically altered to meet the special requirements of certain operations such as grinding, where ferrous contamination is very heavy and quick and easy cleaning is of first importance.

In this new design the magnet is situated in a special chamber which seals it off from physical contact with the operating fluid in the lubricating or coolant system; the trapping cages, however, are fully magnetised whilst the magnet is in this chamber. To de-magnetise the cages for cleaning purposes it is necessary only to lift the magnet from its housing by means of the ring provided. This can be accomplished without interference with any other part of the filter assembly or the circulating system. The contaminated cages which remain in the pipe-line assembly are de-magnetised as soon as the magnet is removed; thus, the ferrous contamination can be quickly flushed from the filter cages by the circulating fluid.

A second outlet has been provided on this filter, so that when it is being cleaned, the contamination can be drawn off into a separate draining bucket. This filter is suitable for systems with a capacity up to 700 g.p.h. Other sizes of filter will be available to deal with systems of larger capacity.

The Work of the Geological Survey of Uganda

A lecture on the above subject will be given by Mr. C. B. Bissett, M.A., B.Sc., D.I.C., at 3 p.m., on October 31, 1946, in the Cinema Hall of the Imperial Institute, South Kensington, S.W.7. The lecture will be illustrated and will be followed by a discussion. Sir Bernard Bourdillon, G.C.M.G., will occupy the chair. This is the fifth lecture of the series dealing with recent progress in geological investigation and mineral development in the Colonies. No tickets of admission are required.

The History and Present Status of Emission Spectroscopy as Applied to Industry

By John Convey, F.Inst.P.

The successful progress of an organisation or society is governed by the ability of its members to solve the problems of to-day with the knowledge gained from similar events experienced in the past. As an aid to this end all business-like groups prepare periodically, inventories of their undertakings both successful and otherwise. Recently the Industrial Spectrographical group of Great

Britain was inaugurated and perhaps many ask the question—what is the present status of spectroscopy as applied to industry? To consider profitably an answer to this question it is necessary to take an inventory of certain aspects of the history of spectroscopy. It is this background which the author presents and upon which spectroscopy in industry has been established as a laboratory control.

THE broad history of science may be described as the story of man's conquest of his material resources by means of new tools, machinery and other devices. His knowledge of these material resources has developed through his innate desire to compare substances from the point of view of some particular property. In physics such a comparison is dependent exclusively upon judgments of perception, and this is especially so in the study of spectroscopy. It is well known that very few instruments have played a role comparable with that of the spectroscope in the development of the modern conception of matter.

The term spectroscopy is quite young as Schuster is credited with the conception of the word in the year 1882. However, the history of spectroscopy is much older and its gradual introduction and establishment in industry as a laboratory control presents one with a very interesting story.¹ As history is commonly described with the aid of some chronological presentation of events, Fig. 1 has been prepared to illustrate the evolution of the spectrochemist. From this illustration the reader obtains at a glance the journey of applied spectroscopy, from the alchemist to the spectrochemist, under the guidance and direction of many outstanding scientists.

The Historical Foundation of Spectroscopy

Chemistry in the middle ages was essentially associated with the alchemist. These alchemists were misguided though serious research workers, seeking to discover the *materia prima* of matter with which

they hoped to transmute the baser metals into silver and gold. They worked with varying amounts of philosophy, astrology, magic and mysticism. These ingredients they blended together with a liberal share of imagination. It was a great speculative age and with the alchemist one sees the birth of modern chemistry.

different refractive indices, an observation which was made by Sir Isaac Newton (1642–1727).

Newton's interest in glass lenses and the construction of telescopes directed him to his famous dispersion experiment with which he laid the foundation stone of spectroscopy. In 1666 he demonstrated that a beam of sunlight

was dispersed by a glass prism into a coloured band which he called a spectrum.² Fig. 2 illustrates

simply, Newton's dispersion experiment.

He discovered that white light is a mixture of many colours and, although the refractive index is different

for rays of different colours, it remains constant for rays of the same colour. This coloured band found by Newton is now commonly known as the visible spectrum, and it was many years later when scientists discovered that the spectrum extended beyond the visible region.

In 1800 the British astronomer, W. Herschel,³ found the infra-red spectrum when searching for a method of viewing the sun to the best advantage with large telescopes. He observed that solar radiation exerted a heating effect which he demonstrated by passing a black bulb thermometer through the spectrum from the violet to a position beyond the visible red end.

² Newton, I., *Trans. Roy. Soc.* (1672).

³ Herschel, W., *Phil. Trans.*, 90, 255, 284, 293, 437 (1800).

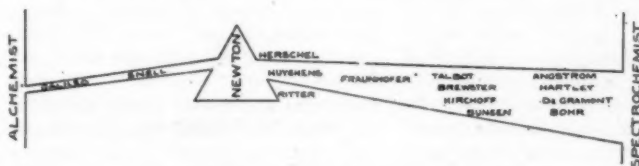


Fig. 1.—The evolution of the spectrochemist.

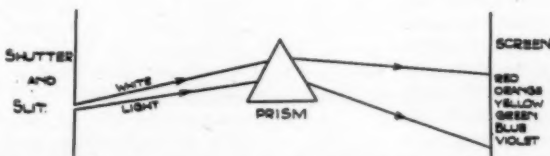


Fig. 2.—The dispersion of white light by a prism.

In the 16th and 17th centuries science was beginning to depend more and more on direct observation than on speculative hypothesis. In this age Galileo, who is known as the father of experimental science, may be regarded as the initiator of spectroscopy when he began his observations and studies of glass lenses. Through the combination of two or more lenses he invented the first telescope. Prior to the work of Galileo, very little was known of optics. Later, W. Snell (1591–1626), as a result of the measurement of angles of incidence and refraction, discovered the law of refraction of light—namely, that the sines of the angles of incidence and refraction have a constant ratio. He failed to detect that light rays of different colours have

¹ Baly, E. C. C., *Spectroscopy*, Vol. I, Chs. I and II; Longmans, Green & Co., London, 1924. Twyman, F., *The Spectrochemical Analysis of Metals and Alloys*; Chem. Pub. Co., N.Y., 1941. Sawyer, R. A., "Experimental Spectroscopy"—Prentice-Hall, 1944, New York.

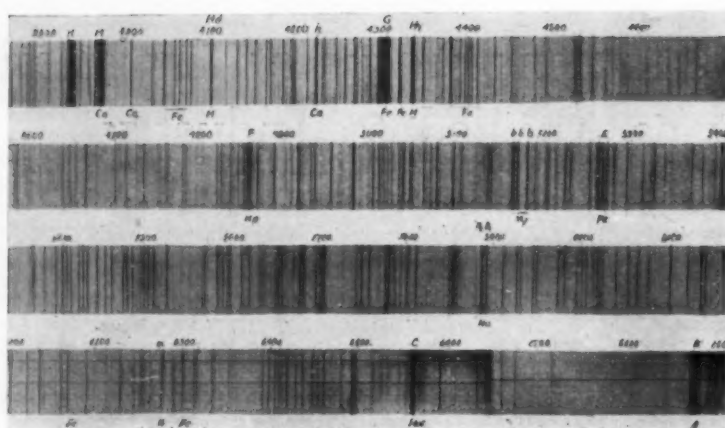


Fig. 3.—The visible solar spectrum.

The heating effect increased from the violet to the red and reached a maximum temperature beyond the red end of the spectrum. He had discovered the infra-red spectrum, but he did not associate his discovery with the nature of visible light. In more recent times the infra-red spectrum has been investigated by many authors⁴, then established and employed in industrial laboratories as an analytical tool.

At the beginning of the 19th century, the ultra-violet spectrum was discovered and examined by Scheele, Ritter⁵ and Wollaston⁶, who observed that silver chloride was blackened when placed in the invisible part of the spectrum beyond the visible violet. This discovery laid the foundation for the photography of spectra, namely, spectrography.

From the time of Newton until the beginning of the 19th century spectroscopy progressed very slowly, although scientists were interested in the nature of light. Unfortunately, due to the poor optical quality of the glass prisms used by Newton, he failed to notice that the solar spectrum was not perfectly continuous. About one hundred and fifty years after Newton's distinguished experiment, Wollaston⁶ in 1802 observed that the visible solar spectrum was crossed with a number of black vertical lines. The study and significance of these black lines was left to Fraunhofer,⁷ by whose name the lines are now known. With various prisms and by improving the form of his apparatus, Fraunhofer demonstrated that the black lines have a definite and fixed position in the solar

spectrum. Although he could not explain the actual physical nature of the lines, he recognised their importance as possible standards for the determination of the refrangibility of different coloured rays. As an optician he could then compare accurately the dispersion factors of different glasses. Fraunhofer mapped about 700 of the black lines of the solar spectrum and labelled eight of the more important ones with the letters of the alphabet, A (red) to H (violet). Fig. 3 shows the solar spectrum crossed with numerous Fraunhofer lines in the visible region 3,900 to 6,900 Å.

Becquerel⁸ and Draper⁹ in 1842 independently photographed the ultra-violet solar spectrum and observed the existence of Fraunhofer lines in this spectral region.

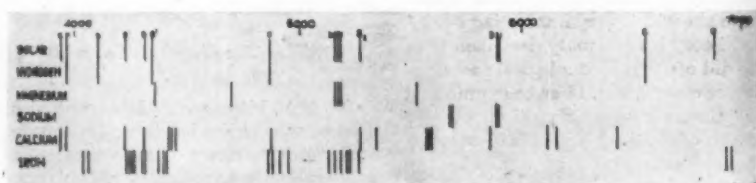


Fig. 4.—Spectrograms of sun, hydrogen, magnesium, sodium, calcium and iron.

From a study of the behaviour of fine slits and their associated diffraction patterns, Fraunhofer¹⁰ produced the first transmission grating. Fortified with the pioneer work of Grimaldi on diffraction in 1665, Huyghens and his wave theory of light in 1678 and its ultimate certification by Young and Fresnel many years later in 1801, Fraunhofer decided to investigate and measure the actual wavelengths of

spectral lines. In this study he successfully measured with great accuracy the unresolved sodium D lines and several other Fraunhofer lines. This work provided science with the basis for a critical comparison method of the spectral results of different observers. In other words, Fraunhofer is the founder of the modern exact science of spectroscopy.

Recognition of Characteristic Spectra

Although Fraunhofer observed the possible identity of the yellow sodium doublet with the two dark D lines in the solar spectrum, the identity and recognition of the Fraunhofer lines remained a secret for many more years. In 1823 J. F. W. Herschel¹¹ in his search for a homogeneous flame for microscopical work noticed that when certain coloured flames were examined spectroscopically that the light was resolved into discontinuous spectra: bright spectral lines superimposed on a dark background. In like manner W. H. F. Talbot¹² recognised that certain salts when admitted to a flame emitted spectral lines that were characteristic of the particular salt. He recorded the individual characteristics of the atomic spectra of sodium, potassium, strontium, silver, gold and copper, although he apparently failed to recognise the physical significance of his results. It was in 1832 that Brewster¹³ made the first attempt at qualitative chemical analysis whereby materials were distinguished by their absorption spectra. His experiments led to the conclusion that the original

⁴ Sawyer, R. A., "Experimental Spectroscopy" 277, Prentice-Hall, New York (1944).

⁵ Ritter, J. W., *Ann. d. Physik*, **12**, 409 (1803).

⁶ Wollaston, W. H., *Phil. Trans.*, **92**, 365 (1802).

⁷ Fraunhofer, J., *Gilberts Ann.*, **56**, 264 (1817).

⁸ Becquerel, E., *Biblio. Un. Genève*, **40**, 341 (1842).

⁹ Draper, J. W., *Phil. Mag.*, **3**, 21, 348 (1842).

¹⁰ Fraunhofer, J., *Ann. d. Physik*, **74**, 837 (1823).

¹¹ Herschel, J. F. W., *Trans. Roy. Soc., Edin.*, **9**, 445 (1823).

¹² Talbot, W. H. F., Brewster, J., *Science*, **5**, 77 (1826).

¹³ Brewster, D., *Trans. Roy. Soc., Edin.*, **12**, 519 (1834); *Rep. Brit. Ass. 2nd Meet.*, p. 320 (1832).

characteristic spectra by Talbot, Wheatstone, Herschel, Helmholtz and the introduction of photography into spectrographic procedure by Draper and Becquerel, Kirchhoff¹⁴ in 1860 produced his theory of the constitution of the sun based upon his knowledge of the origin of the Fraunhofer lines. He conceived the idea that the sun is surrounded by a layer of vapours of many substances which act as filters of the pure white light emitted from the incandescence of the body of the sun. These filters absorb from the white light those rays which correspond in their periods of vibration to those of the component molecules of the vapours, and such absorption is recorded as black lines in the solar spectrum. Kirchhoff thus recognised that the Fraunhofer lines could serve as a source of information with respect to the actual composition of the sun. The presence of an element in the sun being shown by the coincidence of the lines of the elements' emission spectrum with Fraunhofer lines in the solar spectrum, is the basis of modern spectrochemical analysis as employed in industry. Fig. 4 illustrates the coincidence spectra of the elements hydrogen, sodium, calcium, magnesium and iron with the main Fraunhofer lines of the solar spectrum.

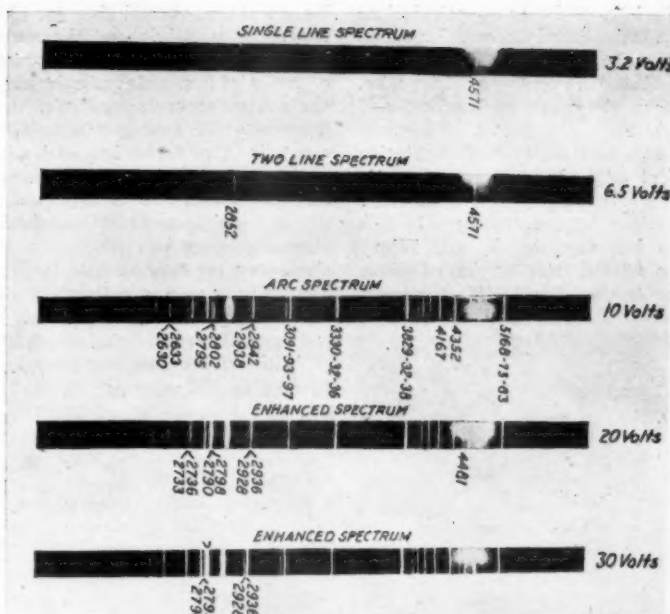


Fig. 6.—Spectrograms showing the development of the magnesium spectrum with changes in excitation conditions. After Ruark and Urey.

the examination and mapping of the emission spectra of terrestrial substances, with the view to putting them on record and to test for their presence

spectral lines. Unfortunately Kirchhoff and Bunsen's work, as with many others, expressed their results in meaningless units. Eventually A. J. Angstrom measured and mapped the normal solar spectrum in 1868, wherein all the wavelengths were expressed in Angstroms (10^{-8} cms.). This unit has been used ever since. Thus a definite stage in the development of spectroscopy was reached and for the first time a standard of reference, placed upon a physical basis, was put on record. The results of different experimenters could be collected and compared relative to each other and with this achievement spectroscopy became an exact science.

Spectroscopy had received a new impetus and, as more and more experimenters entered the field of spectroscopic research, advances were made in every direction. More accurate determinations of Angstrom's normal solar spectrum were measured with the aid of interferometric methods, and eventually the wavelength of the cadmium red line 6438.4696 Å. in dry air at 15° C. and a pressure of 760 mm. of mercury was adopted as the primary spectral standard by the International Union for Co-operation in Solar Research at Menden in 1907. In 1910 it was decided to accept as secondary standards certain iron arc lines which were augmented in 1922 with several neon lines. Since then a number of

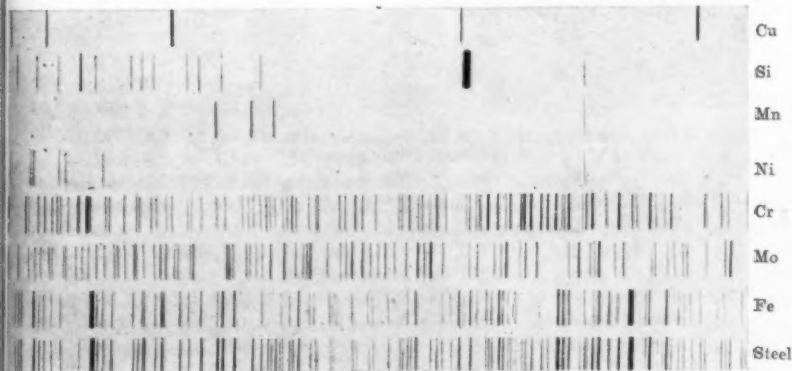


Fig. 5.—Spectrograms of copper, silicon, manganese, nickel, chromium, molybdenum, iron and steel.

In a similar manner, Fig. 5 indicates the qualitative constitution of a steel alloy from the recognition of the co-existence of spectral lines characteristic of the elements iron, nickel, chromium, silicon, manganese and molybdenum, with the spectral lines of a low alloy steel sample.

This discovery of Kirchhoff was followed by an increased amount of work in spectroscopy associated with

in the sun's atmosphere. Kirchhoff and Bunsen¹⁵ performed a long list of spectroscopic investigations among which was the discovery of the elements caesium and rubidium. In all this work the solar spectrum became the standard of reference, particularly since the Fraunhofer lines which are very fine and sharply defined provided ready-made references for the accurate determination of the positions of

¹⁵ Kirchhoff, G. R. and Bunsen, R., *Ann. d. Physik.*, 110, 160 (1860); *Phil. Mag.*, 20 (1860); *Phil. Mag.*, 22, 329 (1861); *Ann. Chim. Phys.*, 62, 452 (1861).

¹⁴ Kirchhoff, G. R., *Phil. Mag.*, 20, 1 (1860); *Pogg. Ann.*, 109, 275 (1860).

compilations of known spectral lines have been published by several authors. The wavelength tables prepared by G. Harrison¹⁶ are worthy of high praise.

Due to the work of Kirchhoff and Bunsen, the development of spectroscopy as a new method of qualitative chemical analysis was ardently pursued. For example, one of the first applications of spectroscopy in the ferrous industry was by Sir Henry Roscoe at the steel-works of John Brown & Co., Sheffield¹⁷. Spectro-

lagged due to several reasons. First, the super-sensitivity of the spectro-scope indicated too readily the presence of traces of impurities associated with the substance under analysis. Quite frequently the analyst was not interested in the trace impurities, and sodium appeared to be omnipresent in all spectroscopic analyses, probably due to lack of care and cleanliness in sample preparation. Secondly, some elements were easy to detect spectroscopically whereas other elements scarcely revealed their presence. This was specially evident when electrical excitation of the spectra was employed. In addition, it was noticed that the spectra of many chemical elements

characteristic arc and spark spectra produced the first attempt at a quantitative method of spectrochemistry.¹⁸ He suggested three possible methods for quantitative spectral analysis by the examination of: (a) Changes in length of spectral lines of an element; (b) the measurement of the intensity of selected spectral lines; and (c) the thickness of the spectral line, as these three spectral line characteristics vary in accord with changes in element concentration in the spectral source. Of these three suggested methods the second is now adopted in modern spectrochemical analysis.

Hartley, Pollock and De Gramont

observed and tabulated those spectral lines which can be detected spectroscopically when an element is present in the source in a very minute amount. Such lines are known as "persistent lines" or "raies ultimes." The detection of these lines provided the analyst with a semi-quantitative method of spectrochemical analysis. However, in spite of this work, spectroscopic methods were used only very sparingly. For example, in 1910 Kayser in his

"Handbuch der Spektroskopie" stated that quantitative spectroscopic analysis had shown itself to be impractical.

During this time, interest in fundamental spectral line analysis had never lagged and ultimately from the celebrated work of Bohr, Rydberg, Sommerfeld, Zeeman, etc., spectroscopy began to reveal the secrets of atomic structure. A new stimulus was given to spectroscopy and progress was greatly accelerated. Fig. 7 illustrates this growth of the subject from the number of spectroscopic research papers published in each of the five year periods from 1800 to 1930.²⁰

Spectrochemistry advanced under the influence of Burns of the National Bureau of Standards of America, who developed the fundamental work of

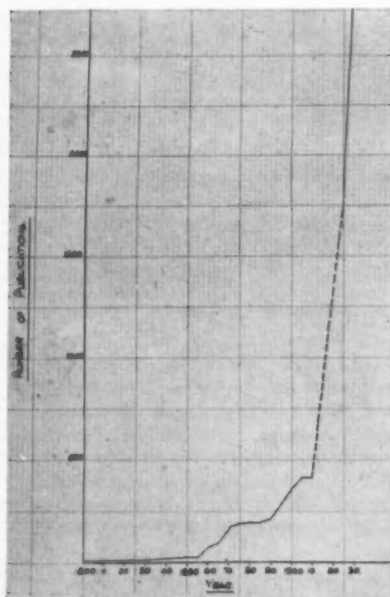


Fig. 7.—Number of spectrographic research papers published in each of the five-year periods from 1800-1930

scopic observation showed that at different stages of the Bessemer process of steel manufacture the spectrum of the converter flame changed. This provided the steel-maker with direct evidence of the progress of the chemical reactions in the melt of steel and a definite indication of its completion. This work has been repeated within the last two years¹⁸ as a means towards the automatic control of the Bessemer process.

The Development of Quantitative Spectrochemistry !

In spite of the initial success and bright prospects of spectroscopy as an efficient tool in the chemical laboratory, interest in its application soon

changed when the type of excitation—i.e., the light source—was changed. Finally, the associated spectra of electrical arc and spark excitation of an element consisted of a rather complex array of lines when compared with the simple spectra which one obtains from ordinary bunsen-flame methods. Fig. 8 is shown as an example to illustrate the above feature of spectral changes dependent upon their method of excitation. The answers to these supposed drawbacks to spectroscopic progress as an analytical method in chemistry represent the development of spectrochemistry during the last twenty years.

Fortunately for applied spectroscopy, a few enthusiasts such as Lockyer, Hartley and De Gramont continued to demonstrate the utility of spectroscopic procedures for qualitative and later quantitative chemical analysis. Lockyer's observations of

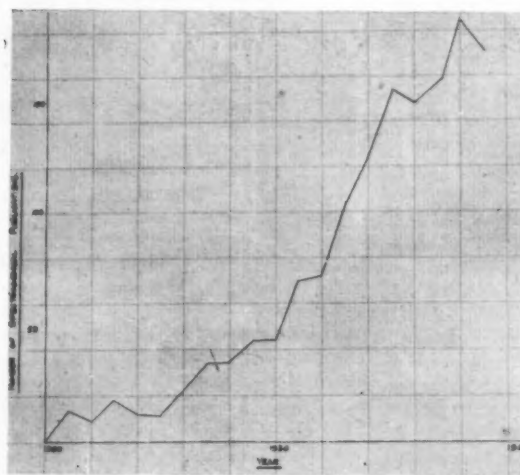


Fig. 8.—Number of spectrochemical papers published in each of the years between 1920 and 1939

¹⁶ Harrison, G. R., Wavelength Tables, J. Wiley & Sons, New York (1939).

¹⁷ Kohn, F., "The Manufacture of Iron and Steel" (1868).

¹⁸ Jarzinski, S. T., J. Iron & Steel Inst., London, Advance Copy (1945).

¹⁹ Lockyer, J. N., *Phil. Trans.*, 163, 255 (1873), *Phil. Trans.*, 163, 639 (1873). Lockyer, J. N. and Roberts, W. C., *Phil. Trans.*, 164, 495 (1874).

²⁰ Sawyer, R. A., "Expt. Spectr.", p. 14-16 (1944).

Hartley, Leonard, Pollock and De Gramont with the eventual establishment of the first general spectrochemical service in the western hemisphere. In 1922, De Gramont experienced the corroboration of his work in a publication by Meggers, Kiess and Stinson²¹, wherein the authors approved and illustrated the successful application of his methods of analysis of nearly pure metals. For many years De Gramont had tried, against much opposition, to popularize the methods in France.

A short time afterwards, F. Löwe²² in Germany revived the "Forgotten Method of Quantitative Spectrographic Analysis," and in 1925 W. Gerlach²³ indicated how successful Löwe had been in Germany at least. From 1925 onwards, the application of spectroscopy spread rapidly to many branches of science and industry. Numerous publications pertaining to the subject appeared in many different languages and journals. Fig. 8 illustrates

this accelerated growth and interest from the number of papers published on spectrochemistry for each of the years between 1920 and 1939, as listed by Meggers and Scribner²⁴.

The development of spectrochemistry was essentially empirical and provided the analyst with a wide variety of methods due to the many possible combinations of spectroscopic factors such as spectrographs, light sources (excitation units), photographic materials, choice of spectral lines and the line densitometry. Of the vast number of papers that have been published on applied spectroscopy, an insignificant number deal specifically or adequately with the physical principles of spectrographic analysis, and industry, especially during the past ten years, has provided problems for spectroscopists that required a closer collaboration between spectral theory and practice. As a result, careful studies of each step in the process of spectrochemistry have been made, particularly the improvement

of spectrographs, densitometers, the control of spectral excitation and the photometric precision of spectral line densitometry. Since 1936, careful and systematic investigations of the errors associated with applied spectrography have been reported by several authors²⁵ and their results provided stimuli for the recent developments and improved methods of analysis. It appears that lack of control of the spectral emission from samples was the major contributor to the total error of an analysis. Improved excitation units were produced and, as spectral source control was established, the photographic aspect of spectral recording has been studied and now appears to be in the process of replacement with the direct photoelectric recording of spectral line intensities. It is interesting to note the main events that made possible the progress as outlined in the preceding sentences.

²¹ Meggers, W. F., Kiess, C. C., and Stinson, F. J., *Sci. Pap., Nat. Bur. Stds.*, 18, 235-255 (1922).

²² Löwe, F., *Z. tech. Phys.*, 5, 567 (1924).

²³ Gerlach, W., *Z. Anorg. Chem.*, 142, 383 (1925).

²⁴ Meggers, W. F., and Scribner, B. F., "Index to Lit. on Spectr. Analysis, 1920-1939," Philadelphia A.S.T.M. pub. (1941).

²⁵ Kaiser, H., *Z. f. Tech. Phys.*, 17, 227 (1936); Sawyer, R. A., Vincent, H. B., *J. Opt. Soc. Am.*, 31, 47 (1941); Sawyer, R. A., Vincent, H. B., *J. Opt. Soc. Am.*, 32, 686 (1942); Crossman, H. H., Sawyer, R. A., and Vincent, H. B., *J. Opt. Soc. Am.*, 33, 185 (1943).

Nature Printing Aluminium Alloy Forgings*

AN investigation into the possibility of nature printing macro-sections of aluminium-alloy forgings was described in our November, 1945, issue. The investigation was carried out in an effort to reduce the amount of labour and materials expended in checking the forging flow-line disposition of large numbers of forgings prior to acceptance by the De Havilland Aircraft Co., Ltd., Hatfield. Various macro-etchants were tried in attempts to produce an etch deep enough for printing. The etchant finally evolved, which at that time was considered to give satisfactory results was:

75 gms. ferric chloride
25 gms. cupric ammonium chloride, in
1 litre water

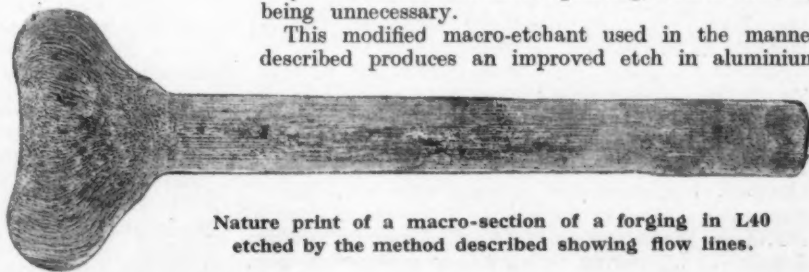
In the light of further experience gained, the etching procedure described at that time has been considerably altered. It was found, for instance, that the above etchant frequently resulted in violent etching, producing an uneven and pitted surface, unsuitable for nature printing, especially when the etchant was newly made up. Various alterations in the strength of the etchant were tried to overcome these difficulties and in an endeavour to obtain sufficient depth for nature printing, while not prolonging the

etching time unnecessarily. The etchant finally evolved is composed of:

40 gms. ferric chloride
13 gms. cupric ammonium chloride, in
1 litre water

The etchant is used hot, at a temperature of 80°-95° C., the section being immersed for two-minute periods until sufficient depth of etch is obtained. The section, after being washed, is then immersed in 45% nitric acid solution, at room temperature, until the adherent brown deposit has dissolved. After washing, the surface may then be used for nature printing, further cleansing being unnecessary.

This modified macro-etchant used in the manner described produces an improved etch in aluminium



Nature print of a macro-section of a forging in L40 etched by the method described showing flow lines.

alloy forging sections deep enough for the reproduction of nature prints. Satisfactory results have been obtained on materials to specifications DTD. 130A, DTD. 364A, and DTD. 423, and BSS. L1, L40 and L45. The accompanying illustration is reproduced from a nature print from a macro-section of a forging in L40 etched by the method described.

* Communication from the Laboratory, The De Havilland Aircraft Co., Ltd.

Some Recent Appointments

MR. W. C. FAHIE, who joined the British Iron and Steel Research Association on the 1st March, 1946, has recently been appointed Head of the Instrument Section in the Physics Department.

Mr. Fahie took a degree in experimental and mathematical physics at University College, Dublin, where he later carried out research on the electrical measurement of short time intervals, band spectrum analysis and various applications of thermionic devices. He was commissioned in the R.A.F. on the outbreak of war, and served as a Signals Officer in the Middle East, Malta and France. He was seconded to the American Air Force as Signals Planner for the invasion of Europe, and was subsequently Signals Planner in Combined Airborne Force Headquarters, where he served until the termination of the war.

MR. REGINALD WORSDALE, Sales Manager, Reynolds Tube Co., Ltd. (Light Alloy Division) since 1934, and Reynolds Rolling Mills, Ltd. since its inception in 1937, has resigned these appointments. Commencing the first of this month, he has taken up appointments as Director and Sales Manager of Birmabright, Ltd., and Sales Manager of Birmetals, Ltd., and is located at Woodgate Works, Quinton, Birmingham.

Prior to joining the Reynold's organisation, Mr. Worsdale served, from 1923 to 1934, with Northern Aluminium Co., Ltd., and he will bring to his new appointments a wide experience and deep knowledge of the light metal industry.

MR. E. S. LITTLE has been appointed to the Board of Directors of Associated Electrical Industries Finance Co., Ltd. In consequence of this new appointment he has retired from the board of the British Thomson-Houston Co., Ltd., but continues to be Comptroller and Secretary of that company.

MR. E. V. HILL has been appointed General Sales Manager of the Northern Aluminium Co., Ltd.; Mr. T. E. Nixon is taking over the management of this company's London Office; and Mr. J. H. Mayes is appointed Manager of the Technical Development Department.

MR. DAVID REILLEY has been appointed General Manager of British Rolling Mills, Ltd.

DR. R. H. GREAVES has retired from his post in the Armament Research Department, Ministry of Supply. MR. C. T. TENISON has been appointed Chairman and Managing Director of William Cummings and Co., Ltd., Glasgow.

MR. F. S. WADDINGTON, of Philips Industrial (Philips Lamps, Ltd.), during the last few weeks, has been elected Chairman of the Organisation Committee of the Society of Engineers, Vice-Chairman of the Finance Committee of the Institute of Welding, and to the Council of the Sheet and Strip Metal Users Association.

MR. C. C. HALL and Mr. A. E. THORNTON have been appointed Special Directors of Firth-Vickers Stainless Steels, Ltd.

MR. B. GRAY, MR. W. D. PUGH and DR. C. J. DADSWELL have been appointed Directors of English Steel Corporation, Ltd.

Mr. Gray has been associated with many branches of the company's activities, and in 1934 was appointed Superintendent of Grimesthorpe Works. During the war he was Chairman of the Tank Castings Design Committee under the Iron and Steel Control, and was responsible for the production of many special types of steel castings for war purposes. He is Chairman of the Research Association of the British Steel Founders' Association. Mr. Gray was appointed a Special Director in 1945.

Mr. Pugh joined the Research Department at Vickers Works in 1926, and later visited metallurgical plants in Germany, Italy, France and the United States. He was Superintendent of The Darlington Forge, Ltd. from the re-opening of the works in 1936, until his return to Sheffield in 1945. He was appointed a Special Director of the company in 1945, and is a Director of The Darlington Forge, Ltd., and of Oughtibridge Silica Firebrick Co., Ltd.

Dr. Dadswell won the Robert Blair Travelling Scholarship, and studied at the Foundry High School, Paris. He became a steel foundry Manager at an early age. During the war he was responsible for the adaptation of foundries for the manufacture of tank parts, and was Chairman of a Ministry of Supply Mission to the U.S.A. to study tank armour. On his release by the Ministry he became Superintendent of drop-forge production, and in 1945 was appointed Special Director in charge of drop-forge, foundry and spring departments of the Corporation.

MR. ARTHUR WHITELEY, Managing Director of the Glanmor Co., Ltd., Llanelly, and Messrs. Thomas and Clement, ironfounders, Llanelly, has accepted an appointment as Controller of Foundries in the British zone in Germany. The appointment is for an indefinite period.

MR. R. J. HOLMES has been appointed crucible and refractory representative in the Midlands for The Carborundum Co., Ltd.; he succeeds Mr. F. Baugh who has resigned to take up another position.

MR. C. G. McAULIFFE, B.A., has relinquished his appointment as Controller of Light Metals in the Ministry of Supply and has taken up an appointment as a departmental manager in the Sales Division of the British Aluminium Co., Ltd. He is located at the Company's Head Offices.

MR. C. HIPWELL, general manager of Redpath, Brown & Co., Ltd., structural engineers, has been appointed a director of the Company.

Associated with Dorman, Long & Co., Ltd., for thirty years, during which he was erection superintendent for the building of the Sydney Harbour Bridge, and later manager of the Company's London Constructional works, Mr. Hipwell became general manager of Redpath, Brown & Co., Ltd., in May last year.

THE HON. R. A. BALFOUR has been elected Master Cutler. He is Assistant Managing Director of Arthur Balfour and Co., Ltd., and a Director of C. Meadows and Co., Ltd., a subsidiary, as well as some of their export companies. He is Vice-President of Sheffield Chamber of Commerce.

MICROANALYSIS

CHEMICAL AND PHYSICAL METHODS

APPARATUS METALLURGICAL APPLICATIONS TECHNIQUE

BEFORE the War there appeared to be every likelihood that Universities in this country would shortly show their approval, in its most concrete form, of the principle of the Sabbatical Year. Much had been written regarding the benefits which would result, and it was widely realised that many of these benefits are intangible, and only to be assessed as long-term profits. There is no doubt, too, that the principle of allowing a man to visit and to work at some place other than his normal laboratory would produce returns in industry also, if rationally applied. There is no question of being able to budget for this in terms of pounds, shillings and pence, but some realisation of the advantages is shown by the frequent comments recently on the need for periodical interchange of staff between academic and industrial organisations. To carry the discussion of the principle further, it is highly probable that if any scientist were released from his work for one year in seven, or even one month in twelve, merely to visit other laboratories without any other obligation, his work would benefit. Such a release might be for a trip abroad. As a rule, such a tour could, in the past, only be carried out as a rather unofficial adjunct to some other primary purpose more directly connected with business. However, visits between laboratories in this country, which might be carried out in shorter periods than a year, should be a more completely recognised part of our scientific life than they are. We do not think it visionary if a firm or a University were to recognise in this way that one of the duties of their staff is to continue to learn: and that this is often just as important as their other function of applying when once they have learned.

Apparatus for Quantitative Inorganic Microanalysis

Part I—Gravimetric Analysis

By Ronald Belcher and Cecil L. Wilson

No matter what may be the demands for expensive apparatus in specialised quantitative microchemical work, much basic apparatus can be constructed by anyone with the most elementary acquaintance with glass-working. Such apparatus is competent for a wide range of determinations, and is certainly sufficient to allow the worker to train himself or to be trained in the exercise of small-scale technique in quantitative analysis. The construction of a range of apparatus amply sufficient for this purpose is described here. Notes on the use of the apparatus are added for the benefit of those who are not already acquainted with the methods of inorganic quantitative microanalysis.

IN various contributions to this Journal^{1, 2, 3} and elsewhere,⁴ it has been shown that most of the apparatus used in small-scale qualitative inorganic analysis can easily be constructed from materials readily available in the laboratory. Similarly, much of the apparatus required for quantitative work can be manufactured by simple methods in the laboratory.

The most important operations, apart from weighing, which are associated with inorganic quantitative analysis are filtration and titration. The former provides the basis of gravimetric work, while the latter controls the practice of volumetric analysis. The worker who is familiar with the construction and use of the simpler types of filters,

pipettes, burettes and titration vessels is therefore competent to provide himself, from laboratory materials, with the wherewithal to practice small-scale work which is so often wrongly assumed to be the prerogative of an expensively equipped specialist laboratory.

The only other essential, the balance, as has been shown elsewhere^{5, 6} can be covered by a reasonably good analytical balance, on which, by the method of swings, weighing can be carried out with an accuracy of ± 0.000025 g. Such an accuracy is sufficient for small-scale methods on samples weighing about 20 mg., and, indeed, with care, may be made to deal with samples not much more than half this weight.

The construction and use of the requisite pieces of apparatus will therefore be dealt with in order as above.

¹ Belcher, *METALLURGIA*, 1944, **30**, p. 280; Belcher and Burton, *ibid.*, 1945, **31**, pp. 272, 319; Belcher and Randall, *ibid.*, **32**, p. 239.

² Wilson, *ibid.*, 1945, **31**, p. 320.

³ Stock and Fill, *ibid.*, 1946, **33**, pp. 272, 323; **34**, p. 51.

⁴ Belcher and Wilson, *Qualitative Inorganic Microanalysis*, Longmans, Green, 1946.

⁵ Wilson, *METALLURGIA*, 1946, **34**, 219.

⁶ Belcher and Godbert, *Semi-micro Quantitative Organic Analysis*, Longmans, Green, 1945.

Filters

Many filters have been described in the literature^{7, 8}, but for the ordinary applications envisaged in this article the types can be reduced considerably in number, it being sufficient to describe a range capable of coping with the usual types of precipitate.

Sintered-glass filters probably possess the most convenient filtering surface, and are not at all difficult to construct. The method of preparation is always the same, regardless of the form of filter in which the plate is finally fixed.

Preparation of sintered-glass filter plates. A quantity of soda glass is ground in a mortar. This operation may be made easier by first drawing the glass into capillaries in the bunsen flame. The resulting powdered glass is sieved through 150 I.M.M. and on 200 I.M.M. The fraction remaining on 150 I.M.M. is again crushed

Fig. 1.—Method of packing sinter plate.

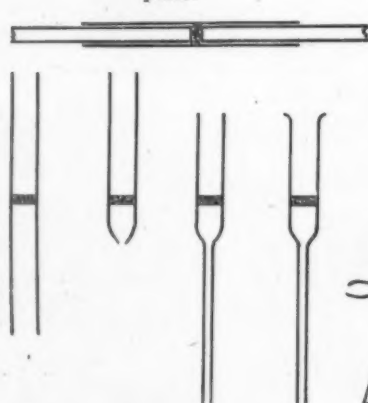


Fig. 2.—Steps in making Pregl filter.

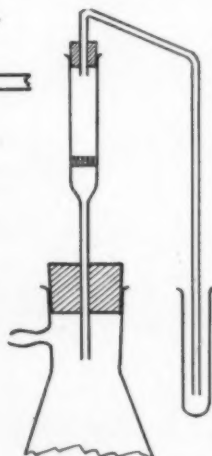


Fig. 3.—Set-up for using Pregl filter.

and sieved, until all the product is sufficiently fine to pass through. The portion passing 200 I.M.M. is discarded.

The 150–200 I.M.M. fraction is boiled with 5N hydrochloric acid to remove iron particles picked up from the sieve. If any contaminating organic matter, e.g., from the sieve, is suspected, a digestion is carried out with chromic-sulphuric acid to destroy this. Finally the glass powder is washed well with water, and dried.



Fig. 4.—Construction of simple King filter.

A 1% solution of water glass is prepared. Some of the powdered glass is mixed with this into a stiff paste. This mixture is packed into a tube of the same glass at the point where the filter plate is required. It is pressed compactly into position by glass rods introduced from each end of the tube, and slightly smaller in diameter, as shown in Fig. 1. Traces of the paste, which have

adhered to the walls of the tube whilst packing the plate in position, are removed using a wad of wet cotton-wool on the end of a stiff wire, or a pipe-cleaner. The tube is placed in an air oven till thoroughly dry. The plate is then heated in the flame of a bunsen burner until sintering occurs. It may be necessary to make a few trials before the correct heating period can be ascertained with accuracy, but knowledge of this is soon acquired

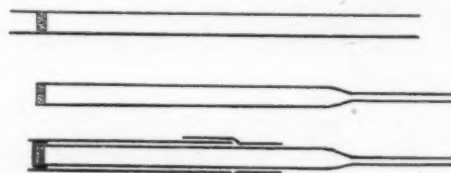


Fig. 5.—Construction of King sintered filter.

with practice. The tube is then allowed to cool in a smoky flame, and finally on an asbestos mat. When cold it is washed copiously with water to remove any excess sodium silicate present.

Pregl filter. A sintered-glass plate is prepared, as described above, in a tube of about 8–10 mm. internal diameter and 10 cm. long. The tube is then drawn out and cut off at a point 1 cm. below the sintered-glass plate, and at this point a tube about 3 mm. in bore and 6 cm. long is sealed on. The other wide end of the tube is cut to a length of about 3.5 cm., and the open end is flared, using a reamer. These steps are shown in Fig. 2.

A mat of asbestos about 1.5–2 mm. thick is packed on to the plate and pressed down tightly with a sharp-edged glass rod. A siphon tube is attached to the filter tube by means of a bung of suitable size, and the set-up is completed as shown in Fig. 3.

Precipitation is carried out in a small boiling tube or other suitable vessel, and the mixture drawn on to the filter, through the siphon tube, by means of suction. If necessary, the filtrate is collected in another tube, placed to receive it, in the suction vessel. This receiver may conveniently be inserted, by the method of Colson,⁹ from the bottom of the suction vessel.



Fig. 6.—Bell-shaped King filter.

King filter stick. The King filter stick is probably the simplest type available. A piece of thick-walled capillary tubing, about 7 mm. in diameter and 1 mm. in bore, is selected. It may be drawn out at one end as shown in Fig. 4, or may be cut plane and fire-polished; in effect, this end is adjusted to a width suitable for attachment to suction. The other end is ground flat on a glass plate with a paste of carborundum and water. A piece of glass tubing is now chosen such that the thick-walled capillary just slides easily in it. A 6–7 cm. length has its edges ground flat with carborundum paste, and after cleaning and drying, it is attached to the capillary tube as shown by a sleeve of flexible rubber tubing.

To use the filter stick, the capillary tube is first withdrawn, leaving the rubber sleeve attached to the outer glass tube. A circle of filter paper with a diameter slightly greater than that of the capillary tube is cut

⁷ Burton, *METALLURGIA*, 1945, 22, p. 285.
⁸ Wyatt, *Analyst*, 1946, 71, p. 122.

⁹ Colson, *ibid.*, p. 322.

with a sharp cork-borer, and is placed symmetrically on top of the rubber sleeve. The capillary tube is then re-inserted, and the paper disc pushed to the other end of the outer glass tube. The edges of the disc should now be wedged tightly between the inner and outer tubes.

The filter stick is generally used in conjunction with a porcelain crucible of about 3 ml. capacity, in which the desired precipitation is carried out. Such a crucible should of course be ignited and weighed prior to using. The narrow end of the filter stick is then attached to suction, and the filtering end placed in the solution to effect filtration. After drawing off the liquid, and washing the precipitate, the capillary tube is pushed downwards in its sleeve, thus extruding the filter paper

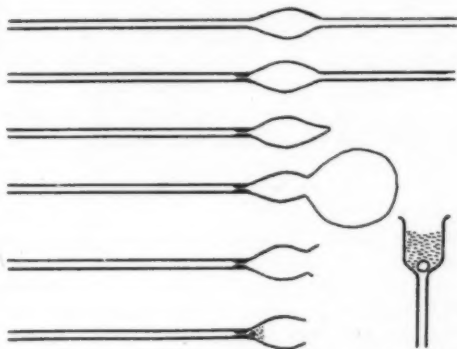


Fig. 7.—Steps in making asbestos filter stick.

Fig. 8.—Kolthoff and Amdur filter.

disc into the crucible. If any particles of the precipitate still adhere to the end of the filter stick, they can be removed by wiping the end with a small piece of moist filter paper held in a pair of forceps. This is also placed in the crucible. The contents of the crucible are then carefully dried, ignited, cooled and weighed. Obviously this method of filtration is only applicable to those precipitates which can be ignited.

Modified King filter stick. In a modification, the thick-walled capillary of the ordinary King stick is

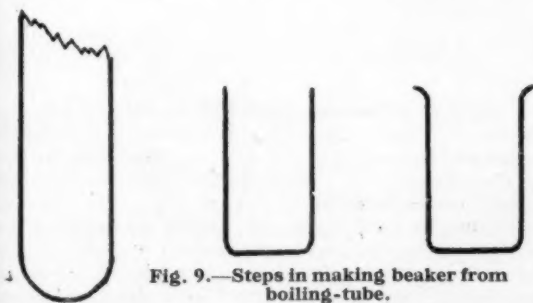


Fig. 9.—Steps in making beaker from boiling-tube.

replaced by a glass tube having a sintered-glass plate at one end. The filter paper disc is still used, and is placed over the end with the sintered plate in exactly the same manner as before. The sintered plate merely gives a more effective filtering surface than the capillary tube. Such a filter stick is often supplied with a bell-shaped filter, the outer tube being shaped accordingly. Such a shape is not essential, and the construction of the filter is simplified by using an ordinary glass tube. Indeed, since

the filter disc must be inserted from the wide end in the bell-shaped form, it cannot be gripped as effectively by the filter stick as in the straight-tube pattern.

For the simple form, a sintered plate is prepared and fixed about 2 to 5 mm. from the end of a glass tube of 5 to 6 mm. diameter and 6 to 7 cm. long. The bearing tube is suitably drawn out at the other end. The edge nearer the plate is then rubbed down with carborundum powder until the filter plate is flush with the end of the stick. The tube is then attached to a water-tap, and water is forced through the plate to wash away adhering particles of carborundum. The stick is fitted into an outer glass sheath as with the original stick, and is used in exactly the same manner. The steps in making such a filter are shown in Fig. 5, while the bell-shaped filter is shown in Fig. 6.

Filter stick with asbestos mat. For dealing with precipitates which are not ignited, but are simply dried prior to weighing, the Emich type of filter, with an asbestos mat, may be used. The steps in its construction may be followed from Fig. 7.

A bulbous piece of tubing, such as the "pipette" remaining after drawing out capillaries from 10 mm. glass tubing, is the starting material. This is carefully constricted close to the bulb at one side, so as to leave only a very fine bore for a short distance. The other tail of the bulb is then drawn off. Where this tail had been, the bulb is blown out to a thin-walled bulb which can be broken off. The jagged edge which remains is now either fire-polished, or ground flat.

An irregular shaped bead of glass is inserted in the bottom of the bulb, over the constriction, and an

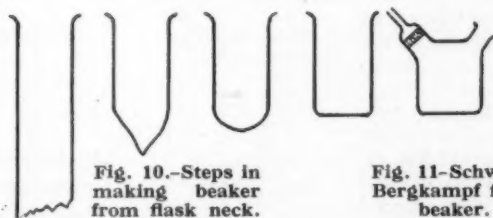


Fig. 10.—Steps in making beaker from flask neck.

Fig. 11—Schwarz-Bergkamp filter beaker.

asbestos mat is packed on top of this. The stick is then washed by sucking distilled water through it until no more particles of asbestos appear in the filtrate. It is then dried and weighed, together with the vessel in which the precipitation is to be effected. Filtration is accomplished as with the King filter stick, but after washing, the vessel and filter stick are dried and re-weighed.

The Dunbar-type filter. The Dunbar filter^{7, 10} has been modified by several workers, and a very simple and useful modification has been described by Kolthoff and Amdur.¹¹ This can be used, either in the upright Pregl fashion, or in the inverted Emich fashion. It can be readily constructed, and applied particularly to precipitates which are subsequently being dissolved up, e.g., for volumetric determination. Its manufacture will be clear from Fig. 8.

A length of 6 mm. tubing is joined to a length of 2 mm. tubing, and the ends are cut to leave the wider piece 1 cm. long and the total length about 2.5 cm. A glass bead is placed in the bottom of the funnel thus formed,

¹⁰ Dunbar, *Ind. Eng. Chem. Anal. Ed.*, 1937, **9**, p. 355.

¹¹ Kolthoff and Amdur, *ibid.*, 1940, **12**, p. 177.

and asbestos is packed above the glass bead to form a filtering mat.

Beakers

For use with filter sticks of the types described, beakers holding about 10 mls. of liquid are required. These can be made by cutting the ends off boiling tubes, heating the rounded ends, and pressing them flat on a charcoal block, as shown in Fig. 9. The edge of the beakers are then flared.

Such beakers may also be made direct from glass tubing, which is usually stouter walled than boiling tubes. It is preferable, indeed, to make them of a resistance glass, such as Pyrex, though this will require a blast lamp.

Yet another alternative is to save the necks of large broken, round-bottomed flasks, which are usually made from a suitable glass, and provide very sound beakers. Stages in such an operation are shown in Fig. 10. The blast lamp will again be required. The neck of the flask is drawn off at a suitable point, and the end of the short tube thus formed is blown out to a test-tube end, using a cork and blowing tube inserted in the open end. The round end is then re-heated and flattened, and the beaker thus formed is already provided with a flared end from the original flask.

Filter beakers. The functions of beaker and filter stick can be combined in an ingenious fashion. For the progressive precipitation of a number of ions, such a combination piece of apparatus, the Schwarz-Bergkampff beaker, is particularly useful. The beaker, shown in Fig. 11, is weighed, and then re-weighed containing the test sample. Solution and precipitation are effected in the beaker. The exit end, bearing a sintered-glass filter plate, is then attached to the inlet of a second weighed beaker, into which the supernatant liquid is filtered, using suction. After drying, the first beaker with its precipitate is weighed, whilst the second beaker is ready for the next precipitation. The process is continued till all the required ions have been precipitated.

This type of apparatus calls for more glass-working skill than can usually be expected in the average worker. For this reason, a simplified form, the construction of which is shown in Fig. 12, has been devised. It is not so convenient as the commercial filter beaker, the assembly

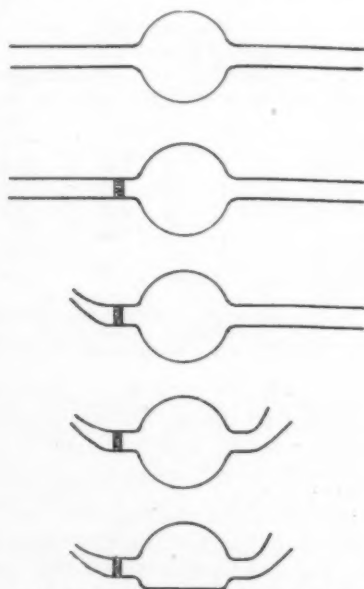


Fig. 12.—Steps in construction of filter beaker.

being somewhat less stable when filtering from one beaker to another. Nevertheless, it is quite efficient, it can be easily constructed, and it illustrates the particular use of filter beakers.

A piece of glass tubing about 5 to 7 mm. in diameter has a bulb about 1 inch in diameter blown in the middle. Alternatively, since such bulbs are often available in the laboratory, one ready prepared may be used instead, with the proviso that it must be made of similar glass to that used for the filter plate. A sintered-glass plate is fixed 5 mm. from the bulb, along one end of the glass tube. This end is then drawn out and bent upwards. The other end of the tube is also bent upwards, but is widened slightly with a reamer. Finally, the bottom of the bulb is heated, and pressed down on a charcoal block to produce a flat bottom.

As a simpler alternative, the filter plate may be replaced by a constriction, a glass bead and an asbestos pad, but this is by no means so satisfactory, as it is easy to shift the pad, and once this has happened the filter beaker must be discarded.

Willstätter nail. The Willstätter "nail" is used as shown in Fig. 13, being inserted in a 1 in. funnel so that the end protrudes below the tip of the funnel. The latter is inserted in a bung fixed in a side-arm test tube, so that filtration may be accomplished under suction.

The head of the nail is about 8 to 10 mm. across, and is produced by fusing the end of a piece of 2 mm. glass rod, and pressing the hot end on a charcoal block. A filter paper disc about 1 mm. larger in diameter is placed on top of the head. This is moistened with water, and pressed down firmly with a glass rod. The mixture to be filtered is poured on to the paper, taking care not to lose any precipitate over its edge. When filtration and washing are complete, the nail is pushed upwards, and the paper with precipitate transferred to a crucible for ignition. If any precipitate overflowed the edge of the paper, and still adhered to the sides of the funnel or the nail, it may be removed by wiping as in the case of the King filter stick.

This method of filtration is best used for somewhat larger quantities than are usually being dealt with in the other methods described, since the risk of loss is greater than in the earlier determinations.

Using the apparatus described in this article, the worker will find it possible to accomplish small-scale determinations on practically all the normal procedures of gravimetric analysis. With the practice thus obtained, he will be able to decide for himself when it is necessary to further his experience and enlarge his range by the addition of further and more complex apparatus. But the authors are concerned to stress that it is possible for any worker, in any normal laboratory to become proficient in the methods of small-scale analysis without any outlay whatever in the way of additional apparatus.

Turning from the field of gravimetric determinations to that of volumetric work the problem is equally simple. Using glass tubing and stock pieces of apparatus which are cheap or readily available, a complete range of efficient volumetric apparatus may be built up. In the second part of this article the production of such apparatus will be described.



Fig. 13.—Willstätter "nail."

Effect of Variations in Composition and Heat-treatment on Some Properties of 5% Chromium-Molybdenum-Titanium Steels

By G. F. Comstock

THE hardness, tensile properties, notch impact resistance and microstructure, weldability, high temperature oxidation, and time for rupture under stress at high temperatures, are reported for thirty-one different 5% chromium-molybdenum-titanium steels, some of commercial manufacture and some of special composition prepared in the laboratory, heat-treated in several different ways. The various steels contained about 4-6% of chromium and 0.5% of molybdenum, and were subdivided into four groups containing:—(1) normal manganese and silicon; (2) high silicon (0.83-1.1%); (3) high manganese (0.76-1.42%); and (4) high silicon and manganese (0.93-1.03% silicon, 0.81-0.98% manganese). The titanium-carbon ratio varied from 2.9-9.8. In Table I are given the tensile results on forged bars of sixteen of the steels normalised at 925° C. The effects of variations in manganese, silicon, phosphorus, molybdenum, nitrogen, aluminium and the titanium-carbide ratio are discussed.

The two chief conclusions drawn from the investigation are that, with titanium-carbon ratios between 3.5 and 5.5 in the 5% chromium-molybdenum-titanium steel, better notch toughness and high temperature rupture strength are obtained than with higher titanium, together with satisfactory ductility and restriction of air hardening, and that silicon about 1% in these steels of 3.5-5.5 titanium-carbon ratio gives superior resistance to oxidation, and need not impair their notch toughness, high temperature rupture strength, or other properties, if the manganese content is about 0.75-1.0% and the steel is tempered at 730° C. without annealing or normalising, after hot working at a reasonably low temperature so as to avoid a coarse grain size.

It was also concluded that although titanium-carbon ratios above 6 may be required to eliminate air hardening at 1,065° C., air hardening at 925° C. is suppressed by titanium-carbon ratios above 4. With ratios above 3, air

impact values can be made if the silicon content is below 0.6% or the manganese above 0.7%, the steel is normalised before welding and annealed at 730° C. afterwards, and the welding current is not applied too long. Oxidation resistance is improved slightly by titanium, not by high manganese, and greatly by more than 1.2% silicon. The pitting type of scaling that occurs with moderate rates of oxidation was not found on titanium steels.

TABLE I—TENSILE TEST OF FORGED STEEL CONTAINING 5% CR AND 0.5% MO NORMALISED AT 925° C.

No.	Composition				Ti/c Ratio	Yield Strength Tons per sq. in.	Ultimate Stress Tons per sq. in.	Elongation % on 2 in
	C	Mn	Si	Ti				
NORMAL MANGANESE AND SILICON—								
1 ...	0.07	0.40	0.34	0.20	2.9	49.5	73.1	14
2 ...	0.08	0.30	0.22	0.30	3.8	15.3	28.7	38
3 ...	0.09	0.58	0.30	0.49	5.4	13.3	27.8	38
4 ...	0.07	0.41	0.32	0.54	7.7	14.2	26.9	41.5
HIGH SILICON—								
5 ...	0.08	0.45	0.83	0.27	3.4	21.8	37.7	32
6 ...	0.08	0.44	1.10	0.36	4.5	20.5	33.8	33.5
7 ...	0.08	0.53	0.83	0.41	5.1	17.8	31.5	37.5
8 ...	0.08	0.42	0.92	0.56	7.0	15.1	26.0	25
HIGH MANGANESE—								
9 ...	0.12	1.42	0.66	0.58	4.8	43.7	52.8	16.5
10 ...	0.09	0.89	0.33	0.53	5.9	14.8	28.9	39.5
11 ...	0.08	0.98	0.30	0.60	7.5	13.7	27.8	39.0
12 ...	0.13	0.76	0.52	1.28	9.8	16.7	26.6	26.7
HIGH SILICON AND MANGANESE—								
13 ...	0.08	0.90	1.03	0.30	3.8	23.8	41.5	29.0
14 ...	0.08	0.98	0.33	0.34	4.3	21.0	35.4	34.0
15 ...	0.09	0.92	1.01	0.52	5.8	18.1	30.1	37.5
16 ...	0.08	0.81	0.93	0.56	7.0	16.6	28.5	39.0

hardening is not over 250 Brinell on cooling from 925° C., except with high manganese and low silicon, or not over 160 Brinell with above 0.75% silicon. In steels with over 0.75% silicon, the transition temperature from low to high notch sensitivity is between room temperature and zero with titanium-carbon ratios below 5.5 and above room temperature with higher titanium-carbon ratios. Higher than normal phosphorus, molybdenum, and aluminium in these titanium steels promote notch sensitivity, but about 0.08% phosphorus might be allowed with manganese up to 0.80% and low silicon, or with low titanium-carbon ratio. Nitrogen tends to reduce the effective titanium-carbon ratio.

The 5% chromium-molybdenum-titanium steel may be welded without hardening to above 200 Brinell if the welds are annealed at 730° C. The notch sensitivity of welds tends to be high, but flash welds with fairly good

stress-rupture tests at 650° C. are lower for annealed commercial 5% chromium - molybdenum - titanium steels with titanium-carbon ratios of 5 to 8 than for similar steels without titanium and with either 0.5% maximum silicon or with 1-2% silicon. With titanium-carbon ratios of 3.8 to 5.1 with silicon from 0.22-1.03%, annealed at 730° C. instead of being normalised, 5% chromium-molybdenum steels with titanium have higher strength rupture stress at 650° C. than similar steels without titanium. After being under stress for over 2,000 hours at 650° C., these titanium steels have excellent notch impact resistance.

The tensile, hardness and impact properties of the steels investigated annealed at 730° C. are satisfactory, so that normalising is not required for them.

From American Society for Metals, 1945, Preprint No. 4, pp. 1-30.

New Aluminium Alloys Containing Small Amounts of Beryllium

By R. H. Harrington

TWO new heat-treatable compositions were investigated, consisting of aluminium-copper-beryllium with the copper and beryllium in the critical ratio of 7 to 1 and aluminium-copper-beryllium-cobalt with the cobalt and beryllium in the critical ratio of 6.5 to 1. Beryllium in excess of about 0.75% in the first series of alloys tended to cause a decrease in the useful properties of these alloys, while in the second series of alloys, keeping the copper constant and increasing the amount of cobalt-beryllium resulted in an increase in elastic properties and hardness. Beryllium, however, in excess of 0.7% and cobalt in excess of 4.5% resulted in alloys difficult to cast and of inferior properties.

Experiments were carried out on the four alloys whose compositions are given in Table I. Compositions 1 and 2 were selected to show the increase in elastic properties due to a ratio 7 to 1 for copper to beryllium, and compositions 3 to 4 to show the effect on tensile properties of an increase in the ratio to 6.5 to 1 for cobalt to beryllium. Individual samples of each alloy were quenched from 4 hours solution-treatment at temperatures of 510°, 520°, 530°, 540°, 550°, 560° and 570° C., reheated and aged at each of the following temperatures, 50°, 75°, 100°, 125°, 150°, 175°, 200°, 225°, 250°, 275° and 300° C. Hardness values for each treatment indicated the most effective solution and ageing temperatures, and the effect of time at such temperature was determined using periods of 2, 4, 8 and 20 hours in each case. The preferred precipitation hardening treatments for castings for each alloy are also given in Table I, together with the tensile properties and hardness obtained after such treatments.

Tests also showed all four alloys to naturally age very rapidly with maximum effects from 540° C. solution treatment, and that four weeks practically completed natural ageing. To demonstrate cold workability it was found that 1 in. diameter solution-quenched cast rods could be cold-swaged by 50, 50, 23 and 10% respectively for the four alloys. As regards thermal stability, since standard sand casting aluminium alloys were aged

at 150° to 160° C. for maximum properties, and aluminium-copper-beryllium sand castings were aged at 200° C. for similar properties, 6 hours over-ageing at temperatures ranging from 225° to 300° C. were required to lower the hardness of the new alloys into the range of hardness of the standard alloys, thus indicating higher thermal stability.

TABLE I—COMPOSITION, TREATMENT AND PROPERTIES OF ALUMINIUM-BERYLLIUM ALLOYS.

Alloy No.	Composition	Preferred Heat Treatment	Proportional Limit Tons per sq. in.	0.2% Yield Stress Tons per sq. in.	Ultimate Stress Tons per sq. in.	Elongation %	Rockwell Hardness B.
1	3.8 Cu-0.2 Be-Al	4 hrs. 540° C., W.Q., 8 hrs. 200° C.	9.8	14.2	18.3	4	45-48
2	3.5 Cu-0.5 Be-Al	4 hrs. 540° C., W.Q., 8 hrs. 200° C.	11.1	15.6	19.6	5	55-57
3	3.8 Cu-0.2 Be-1.3 Co-Al	4 hrs. 540° C., W.Q., 6 hrs. 200° C.	11.1	15.2	19.2	3	58-62
4	3.5-0.5 Be-3.2 Co-Al	4 hrs. 540° C., W.Q., 2 hrs. 200° C.	14.2	17.8	18.5	1	71-75

In general, results showed that the new alloys of aluminium-copper-beryllium, with and without copper, were outstanding for their unusually high tensile properties combined with high thermal stability and oxidation resistance. When compared with the 4% copper-aluminium standard alloy, alloy 1 showed the marked beneficial effect of small additions of beryllium.

thermal stability and high oxidation resistance.

The new compositions were also satisfactory in foundry practice when cast by gravity sand casting, lost wax precision casting and centrifugal casting methods. Foundry experience tends to favour alloy 3 (3.8% copper-0.2 beryllium-1.3% cobalt) for its casting properties.

Compression Testing of Magnesium Alloy Sheet

By A. A. Moore and J. C. McDonald

FACTORS encountered in compression testing of sheet-like specimens of magnesium alloys are discussed, and a rapid method of autographic stress-strain recording is presented which is comparable in speed to that obtained under similar conditions in a tensile test. The accuracy of strain-recording is considered good, but the stress measurement includes the frictional component inherent in any means of support.

The chief problem in sheet compression testing is to prevent buckling by using lateral support. Any materials in compression expand laterally even in the elastic range and the amount of frictional load developed depends on

the supporting surface and its rigidity. Several methods of supporting sheet specimens have been used, including the pack method and sandwich methods using smooth flat surfaces clamped to the specimen. On some magnesium alloys it has also been found that rollers give less friction and were preferable to flat polished surfaces. Precise determinations of strain are made on gauges or autographic recorders.

A rapid method of obtaining an autographic stress-strain curve has been developed. The arrangement includes a high-temperature extensometer with the regular adaptors replaced by short rigid legs equipped with knife edges which are clamped against the specimen with spring

From American Society for Metals, 1945, Preprint No. 12, pp. 1-14.

From Bulletin Amer. Soc. Testing Materials, 1945, No. 135, pp. 27-30.

TABLE 1.—COMPOSITION OF MAGNESIUM-BASE ALLOYS TESTED.

Alloy	Al	Mn, Max.	Zn	Fe, Max.	Ni, Max.
Dowmetal F.S.I. . . .	3.0	0.2	1.0	0.005	0.005
Dowmetal J.L. . . .	6.5	0.15	0.9	0.005	0.005
Dowmetal M. . . .	—	1.2	—	—	—
Dowmetal 0-1	8.5	0.15	0.5	0.005	0.005

TABLE 2.—COMPARISON OF VARIOUS SUPPORTS, TO NO SUPPORT.

Alloy	Gauge in.	Direction of Testing	Yield Strength, lb. per sq. in.			
			Roller Supports		Pack	Specimen 2 in. Long No support
			Plain Bar	Reduced Section Bar		
F.S.I. (a)	0.250	Long.	15,400	15,300	15,600	14,600
		Trans.	16,300	15,900	15,900	15,000
F.S.I. (A)	0.250	Long.	27,600	27,800	27,900	26,900
		Trans.	31,200	31,300	31,300	30,300
J.L. (a)	0.250	Long.	15,100	15,100	14,700	14,800
		Trans.	15,700	15,900	15,500	15,400
J.L. (A)	0.250	Long.	25,100	25,500	26,300	24,800
		Trans.	29,300	29,700	30,300	28,500
M. (a)	0.250	Long.	11,800	11,500	11,600	11,100
		Trans.	10,900	10,900	10,900	9,900
F.S.I. (a)	0.032	Long.	17,700	17,100	17,600	—
		Trans.	20,100	18,600	18,200	—
F.S.I. (A)	0.032	Long.	31,400	31,800	(I)	—
		Trans.	32,800	33,200	(I)	—

(I) Buckled below yield strength. (a) Annealed sheet. (A) Cold-rolled.

pressure. Strain is measured over a 1 in. length in the middle of the specimens, and strain readings obtained from opposite sides of the specimen are transmitted to the extensometer. Since a single-sheet jig restrains bending in all but one plane, a close approximation of the compression strain is obtained, even if some bending is present. Modulus values obtained varied about 200,000 lb. per sq. in. from a mean value of 6,500,000 lb. per sq. in.

The regular rectangular test specimen was tried first, but it was found that at least 0.045 in. extra was required on magnesium sheet alloys in addition to the jig length of 2.60 in. For 0.064 in. diameter rollers this left 0.077 in. of unsupported material. Buckling was met with on some of the stronger alloys at a thickness of 0.032 in. when 0.064 in. rollers were used. Reducing the section of the test specimen in the middle allowed sheet 0.025 in. thick to be tested before buckling occurred between the rollers. Flat plate supports were also tested with reduced section specimens and material down to 0.016 in. thick was tested successfully.

Tests on the alloys given in Table 1 were carried out with the new apparatus using various types of supports. In Table 2 are given the results obtained from $\frac{1}{4}$ in. plate tested as a single sheet with roller supports, as a pack, and unsupported. The average of these tests showed unsupported specimens to have a yield strength 4.4% lower than the average of the values obtained with reduced section specimens supported by roller surfaces. Sheet 0.125

in. and 0.064 in. thick were tested for a comparison of single sheet results

with the pack method and good agreement was obtained. Tests on reduced-section specimens of 0.016 in. FS-1a and FS-1h sheet showed that those tested with roller supports buckled while those tested with flat plates did not buckle.

In general, it was found that on commercial Dowmetal sheet alloys the regular pack method with supporting rods $\frac{1}{4}$ in. apart could be used for 0.064 in. sheet. The 0.032 in. sheet buckled. In single-sheet specimens the following limiting minimum thicknesses were found: (a) Flat plate supports, reduced section specimen—less than 0.016 in., (b) 0.064 in. diameter roller supports, rectangular specimen—0.032 in., (c) 0.064 in. diameter roller supports, reduced section specimen—0.025 in.

It was also noted that some magnesium sheet alloys showed a sharp-kneed compressive stress-strain curve accompanied by pronounced Lueder's lines similar to tension on mild steel.

Time-temperature Relations in Tempering Steel

By J. H. Hollomon and L. D. Jaffe

THE effect of tempering temperature and time upon the properties of quenched steel is a subject of great practical importance as well as of considerable theoretical interest. As few quantitative studies of the hardness of quenched steel tempered over wide ranges of temperature and time have been published, it was decided to study a series of fully quenched steels differing only in carbon content, tempered over a wide range of time at temperatures from room to just below the critical temperature in order to obtain more systematic knowledge of the effects of carbon content, temperature and time. It was also decided to establish a method of finding the various combinations of temperature and tempering time that produce the same hardness.

For the experimental work, six plain carbon steels, whose compositions are given in Table I were used. These steels were fully quenched to martensite, and tempered at temperature ranging from 100°–700° C. for 10 sec., 90 sec., 15 min., 2½ hrs., and 24 hrs. All specimens were quenched in water after tempering, and were then ground to a depth of 0.050 in. on a wet surface

grinder and four Rockwell C hardness measurements made on each.

From the results obtained it was found that the hardness was a function of the parameter $T(\log t/t_0)$, equivalent to $T(c + \log t)$, where T was the absolute temperature, t the time, and t_0 and C constants of the steel. This functional relationship was found to hold very closely (within about ± 1 Rockwell C) for all appropriate tempering data, except when graphitization took place and was true whether the initial structure was martensite (with or without retained austenite), bainite or pearlite and whether or not secondary hardening occurred.

The value of the constant C was found to vary somewhat for different steels, and appeared to decrease linearly with increasing carbon content. The important practical application of the relationship, however, was the determination of the various combinations of tempering temperature and time that result in a given hardness when one such combination is known for the steel. For this purpose, it appeared sufficiently accurate (within ± 1.5 Rockwell C over the usual range of times) to use $C = 19.5$ for ordinary carbon and alloy steels (0.25–0.4%

From *Metals Technology*, 1945, Vol. 12, No. 6, A.I.M.M.E., Technical Publication 1831, pp. 1–26.

TABLE I—COMPOSITION OF STEELS.

No.	C	Si	Mn	S	P	Ni	Cr	Cu	Mo
1 ...	1.15	0.09	0.58	0.021	0.012	Tr.	0.01	—	Tr
2 ...	0.89	0.06	0.55	0.020	0.012	—	0.01	0.08	—
3 ...	0.74	0.18	0.66	0.021	0.009	Nil	0.01	—	Nil
4 ...	0.56	0.18	0.54	0.015	0.012	"	0.02	—	"
5 ...	0.31	0.10	0.52	0.026	0.007	"	0.015	0.06	"
6 ...	0.98	0.30	0.30	0.021	0.007	Tr.	0.03	0.055	"

carbon) and C = 15 for tool steels (0.9–1.2% carbon), the times being expressed in hours. On the basis of these values, charts were prepared by which the equivalent time-temperature combinations can be found readily.

For steels showing no secondary hardening, it was found that Rockwell C or Brinell hardness varied almost linearly with the parameter over a considerable range, and that the slope of this linear relationship differed little among the various steels. This permitted of the inclusion in the charts of

a feature that allowed rapid calculation of the hardness obtainable with any tempering treatment (within certain limitations and within an accuracy of ± 3 Rockwell C) when the hardness obtained with only one tempering temperature was known.

In general, the results obtained from the investigation permitted a closer estimation of the hardness that will be obtained with any time and temperature of tempering with much fewer experimental data than were formerly necessary.

Plaster Mould Castings

By N. B. Barnard

PLASTER casting has long been used for small castings, but the period of time required for drying the plaster has precluded its use for commercial production until recently. During the past ten years, however, methods of drying have been developed which make the use of plaster desirable for modern technique. As plaster can now be used economically and as a plaster mould produces smooth, uniform castings of clear definition, close tolerances and intricate design, such castings are being used by industry generally, particularly for electrical apparatus and automotive parts, and present developments indicate that the use of plaster mould castings will continue to increase throughout industry in the future.

In the moulding process the plaster is mixed with other dry elements to give it strength and is then mixed with water. The pattern impression is then established in the mix when it is semi-set, the pattern is withdrawn and the mould baked, cores also made of plaster are inserted, the cope and drag are joined and the casting poured. The requirements of the plaster material are: that it contain sufficient permeability to provide a ready egress for all air and gas in the mould during pouring; that it be sufficiently strong to withstand the metal without distortion until the metal sets; that it be at the same time sufficiently weak

so that it will collapse during the shrinkage of the casting after solidification and thus avoid setting up cooling stresses; and that the material be free from moisture. Before the

has shown distinct promise but the plaster mould casting of steel or cast iron is still in the experimental stage. In casting a particular alloy, it is possible to make several different types of castings from one mould.

The use of plaster mould castings permits reductions in costs through the elimination of scrap. Machining costs are also reduced due to castings being made to closer dimensions. Thinner sections can be designed in such castings because the metal is introduced into the mould under favourable conditions and their relative dimensional accuracy makes excessive machining allowances unnecessary. The elimination of porosity in plaster moulding produces stronger castings and allows such castings to be used where pressures are required. Plaster moulding also lends itself to intricate casting design, permitting freedom of design in the casting and often allowing two or more pieces to be cast integrally.

Plaster mould castings have found many applications in industry. Internal splines, ratchet teeth and stops can be cast and used without machining. Rivets can be cast integrally and gears can be cast in most

TABLE I.—ALLOYS CAST IN PLASTER MOULDS.

Composition and Properties	High Strength Yellow Brass	Manganese Bronze—1	Manganese Bronze—2	Aluminium Alloy
Copper	56-62	55-60	60-68	1.25
Iron	0.75 max.	0.4-2.0	2.0-4.0	—
Aluminium	1.0 "	0.5-1.5	3.0-7.5	Balance
Manganese	0.5 "	0.1-1.5	2.5-5.0	—
Tin	0.5-1.5	1.0 max.	0.5 max.	—
Nickel	0.5 max.	0.5 "	—	—
Lead	0.5-1.5	0.4 "	0.2 max.	—
Zinc	Balance	Balance	Balance	0.5
Magnesium	—	—	—	5.0
Silicon	—	—	—	—
Tensile Strength, min./tons per sq. in.	25	29	42.5	—
Tensile Strength, typical tons per sq. in.	25-31	29-35	42.5-50.0	7-9
Elongation, min.	15%	20%	10%	—
Elongation, typical	15-25%	20-35%	10-15%	0.5-1.5%
Rockwell Hardness	47-75 B	60-80 B	60-85 G	—
Brinell Hardness (500 kgs.)	75-110	90-120	—	—

plaster mixture is added to the flask, all surfaces of the flask and patterns touching the mould materials are sprayed with a parting mixture to prevent sticking when the mould is withdrawn, and quick-drying of the mould (in hours as against days) is achieved through large-volume exhausting of the drying area, without checking or cracking of the mould surface.

The alloys found most suitable for plaster mould castings are yellow brass, two manganese bronzes and an aluminium alloy. The composition and properties of these materials are given in Table I. Aluminium bronze

of the alloys in Table I, so that they can be used in their as-cast condition without machining the bore. Inserts can be cast in place and either depressed or raised lettering can also be produced. Their uniform homogeneous grain size has also made them highly acceptable for use in electronic equipment, for which purposes the slightest porosity or imperfection would preclude the use of castings. The smooth surfaces of plaster mould castings also permit plating and other forms of finishing without a large amount of buffing or other preparation of the surfaces.

From *Materials and Methods*, 1945, Vol. 22, No. 4, pp. 1085-1089.

Silicide Hardened Copper Compacts for Bearings

By F. R. Hensel, E. I. Larsen and E. F. Swazy

HARD bronzes are not suitable for bearing application where high bearing loads and speeds are involved and it is general practice to utilize softer materials for these purposes, such as copper, lead, silver, and tin and lead base white metals, and more recently aluminium-base alloys, preferably supported by a steel backing. The present investigation deals with a new material produced by powder metallurgical methods susceptible to precipitation-hardening.

Preliminary tests were made with compacts containing copper, nickel and silicon in quantities sufficient to form 3 to 5% nickel silicide. It was found that this type of alloy was susceptible to the formation of a soft surface shell when sintered in hydrogen, and that the soft shell resulted from the preferential oxidation of silicon, thereby reducing the efficiency of age-hardening by the nickel silicide compound. A series of tests was made with various addition agents, in order to decrease the rate of preferential oxidation, and it was found that phosphorus was most beneficial. The following composition was finally accepted as standard: 2.4% nickel, 0.8% silicon, 0.3% phosphorus, balance copper.

Compacts were prepared from copper and a prealloyed nickel silicide hardener containing 25% nickel, 7% silicon, 3% phosphorus and 64% copper. This alloy was brittle as cast and could be readily powdered. The blended powders were pressed at 25 to 40 tons per sq. in. and sintering was carried out in hydrogen or cracked ammonia atmospheres at temperatures of 1,000° to 1,040° C. for 1 hour. Optimum properties were obtained by water quenching from 850° C. after a soaking in a non-oxidising atmosphere for 30 to 60 min., followed by ageing for 4 to 6 hours at 450° C. in air.

Tensile properties after heat treatment are given in Table I. The copper powder used in the preparation of D-1206 was minus 300-mesh as compared with minus 200-mesh copper powder used in the preparation of all other specimens. Compressive strengths determined on a special fixture designed to eliminate all non-

axial loads during testing indicated that compression tests were highly sensitive to misalignment but that when great care was taken sintered materials obeyed Hooke's law. A series of tests indicated that there was a linear relationship between density and modulus of elasticity in compression. Improved fatigue tests of 8 tons per sq. in. were obtained when using prealloyed powders, being an increase of 75% over that obtained from compacts made from elemental powders.

hardness of 75 to 80 increased from 17.6×10^{-6} over the range 21 to 100° C. to 21.2×10^{-6} over the range 700 to 800° C.

Amsler seizure tests carried out on compacts sintered, repressed, quenched and aged and having a Rockwell B hardness of 77 to 81 showed the material to be considerably more resistant to seizure than such alloys as copper-lead or tin bronzes. Two types of material, one that was sintered, repressed, quenched and aged and having a Rockwell B hardness of 35 to 40 and a density of 7.74 grams per cc. and one that was sintered, repressed, quenched and aged and having a hardness of 75 to 80 Rockwell B and a density of 8.4 grams per cc. were tested under conditions of considerable

TABLE I.—TENSILE PROPERTIES AFTER HEAT TREATMENT.

Sample No.	Specimen No.	Proportional Limit Tons per sq. in.	Elastic Limit Tons per sq. in.	Ultimate Strength Tons per sq. in.	Elongation %	Reduction of Area %	Density GM/CC.
D1205-C	1	6.4	12.8	22.0	0.997	0.227	7.96
D1205-C	2	7.5	15.2	22.6	1.37	0.687	7.74
D1206-C	3	5.9	17.0	24.8	1.37	0.228	8.34
D1205-E	4	3.5	16.4	27.4	2.34	0.14	8.28
D1205-E	5	4.1	12.8	23.2	0.78	0.228	8.44

D1205-C and D1206-C, sintered, water quenched from 850° C., aged 5 hours at 450° C. D1205-E, sintered, repressed, water quenched from 850° C., aged 5 hours at 450° C.

The electrical conductivity of sintered test pieces having a density of 8 grams per cc. varied from 19.5 to 21% I.A.C.S., and after repressing at 50 tons per sq. in. to a density of 8.3 grams per cc. the conductivity ranged from 20.5 to 21.5%. Quenching of the repressed specimen in water from 850° C. reduced the electrical conductivity to 14.5% and ageing for 5 hours at 450° C. resulted in a conductivity of 23 to 25%. The coefficient of thermal expansion of a compact quenched from 850° C. and aged 4 hours at 450° and having a density of 8.3 and a Rockwell B

severity on the General Motors bearing testing machine. In both cases the bearings ran through the tests without showing distress of any sort and were in excellent condition at the completion of the test. There was no sign of metal to metal contact on the bearing and very few scratches, the latter probably caused by dirt. The shaft also was in good condition. Brightening was evident at high load points, but there was little of the gouging that often occurs with copper-lead bearings on shafts that are not fully hardened.

Corrosion Studies on Electrolytic Chromium

By N. Hackerman and D. I. Marshall

ELECTROLYTIC chromium, stripped from its basis metal, was immersed in aqueous solutions of NaOH, HCl, H_2SO_4 , $\text{H}_2\text{C}_2\text{O}_4$, and NaCl at various concentrations with the last being studied over a pH range from 0 to 11. The metal was used in both the active and passive state and the solutions, saturated either with air, nitrogen, or hydrogen, were maintained at 35° C. The passive metal

showed only isolated instances of attack, while in the active state reaction occurred in all of the media in which the pH could be maintained below 3. With higher pH values the metal generally became passive again after a short time, even in the deaerated solutions. Weight change values were obtained for the active chromium and it was shown by microscopic examination that the type of attack could be related to the medium, the

From *Metals Technology*, 1946, Vol. 13, No. 2, and *A.I.M.M.E. Technical Publication*, 1976, pp. 1-8.

From *Electrochem. Soc. Preprint* 89-15, April, 1946.

concentration, and the relative period of immersion. Short exposures in acid media showed that attack first appeared along the crack network system of the chromium plate and that typical acid etch patterns were observed for

sufficiently long exposures. In alkaline NaCl solutions, isolated points of attack were found which were not related to the crack system. NaOH solutions produced no noticeable change.

Internal and External Hot Tears

By H. F. Bishop and H. F. Taylor

THE defect in steel castings commonly known as an internal hot tear is a crack within the casting resulting from shrinkage and inadequate feeding. The external hot tear, caused by restrained contraction, is visible on the surface. Since these two defects arise from different conditions and are remedied by unlike methods, it is important, since each type has individual characteristics, that they be properly identified when observed on radiographs, so that they can be eliminated in subsequent castings. Typical examples of both types have been examined and are discussed.

The term internal hot tear is applied to a crack-like defect in steel castings not visible to the eye. They are found in imperfectly-fed castings, and differ in appearance from external tears in that they have no particular orientation, may run in all directions and have small cracks branching off from the larger cracks. Since this internal crack is invariably near a shrinkage cavity or a low-density area, it is apparent that they are associated with shrinkage. To determine the effects of inadequate risers on the internal hot tear, a series of plates 8 in. long, 6 in. wide and 1½ in. thick, were cast and fed by increasingly larger risers. As a result of these experiments, it was apparent that the severity of the cracks was reduced as the size of the riser was increased, and when the casting was sufficiently risered, the defect completely disappeared. This leads to the conclusion that the internal hot tear is in reality a form of shrinkage, and can be eliminated by adequate feeding. Radiography has been found to be the only reliable means of detecting internal tears, although it is probable that very severe internal tears, which extend to within a short distance of the casting surface can be found by magnetic powder testing methods, if a very high current is used. No explanation of the mechanics of internal tear formation is advanced, although several theories are being considered.

From *The Foundry*, 1946, Vol. 74, No. 7, pp. 82-87 and 218.

External hot tears have a rough irregular appearance, and form in casting soon after the metal has been poured. They are caused by interference with the normal contraction of the casting, and this interference may be the result of two things—mould resistance, or resistance due to design of the casting where one part is restrained from contracting by other parts of the same castings. A region must also be present in the casting which is lower in strength than the rest of the casting, and this weak area is usually the hottest part of the casting, and is the point at which elongation or failure must occur. Hot areas are found at the gates or risers of the casting, at internal corners, or in heavy sections which are joined to lighter sections. When no hot zones are present, strains are distributed evenly throughout the casting, but if a hot weak area is present, the deformation for the entire casting will occur at this localised area, and may result in a hot tear.

External hot tears are eliminated either by the judicious application of chills or brackets which strengthen the metal, making it capable of resisting the tearing stresses, or by using weak sand or relieving cavities which enable the mould to collapse, thereby relieving the stresses. Severe external hot tears are easily seen on the surface of a casting, but slight tears which may be overlooked in a cursory inspection will be discovered when the casting is sandblasted, radiographed or subjected to a magnetic powder test. On a radiography external tears are roughly parallel, and do not cross. An external hot tear may also occur in a perfectly-fed casting, while an internal hot tear will not.

Polarographic Analysis of Aluminium Alloys

By I. M. Kolthoff and G. Matsuyama

Procedures have been developed for the polarographic determination of

From *Industrial and Engineering Chemistry, Analytical Edition*, October, 1945.

iron, copper, lead, nickel, and zinc in aluminium alloys. The alloy is heated with sodium hydroxide and the solution completed in nitric acid. In the absence of chloride, ferric iron and copper give well separated waves. If the ratio of iron to copper is large, the ferric iron is reduced with hydroxylamine hydrochloride. The lead wave is determined after reduction of the ferric iron and precipitation of copper as cuprous thiocyanate and adjustment of the pH. The nickel and zinc waves are determined after adjustment of the pH of the solution of the alloy, and addition of hydroxylamine hydrochloride, thiocyanate, sodium citrate, and pyridine. Alternate procedures are discussed. The proposed procedures give satisfactory results and are especially recommended in routine analysis. The actual time spent in the total analysis for the five elements will be less than 45 min. in routine work.

Determination of Hydrogen, Carbon and Nitrogen in Magnesium Alloys

By E. G. Bobalek and S. A. Shrader

The analysis of magnesium alloys for extractible, gaseous, non-metallic impurities has been investigated by three methods—extraction with an inert gas, vacuum extraction, and electrical degassing by ion bombardment. The chemical methods of microcombustion for carbon and hydrogen, and micro-Kjeldahl for nitrogen were adapted to magnesium alloys in order to check the reliability of the extraction methods. The gases ordinarily extracted from magnesium alloys are hydrogen, the oxides of carbon, and trace quantities of nitrogen. The results from all methods are consistent in the analyses for these gases. The extraction methods are of greater precision for the determination of hydrogen. However, none of the extraction methods compares favourably in precision with the combustion method for carbon or with the Kjeldahl method for nitrogen.

From *Industrial and Engineering Chemistry, Analytical Edition*, September, 1945.

We have many requests for copies of issues which are out of print. The most difficult to supply are copies of the following issues:—May, 1940; February and May, 1943; February, 1944; August, 1945; and April, 1946. We would appreciate any help from readers in meeting these requests. Send particulars to—"Metallurgia," 31, King Street West, Manchester, 3.

r
s
e
e
n
o
e
s.
n
ne
es
i-
or
ls
r-
ne
es
n-
ne

ly

es
he
of

13;
nd
ny
ese

st,